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CONTENTS

PREFACE

The following chapters cover the ground of a number of lectures given to Cambridge University Extra-Mural audiences. As these varied considerably in type, age and educational attainment the subjects had to be treated in a simple manner and many explanations given that would have been unnecessary if previous scientific knowledge could have been assumed. This being so certain repetitions have been unavoidable, but they have been kept within moderate bounds. Technical terms and expressions have been avoided as far as possible and not made use of without explanation.

The term " Science " is used in a restricted sense to include mainly Physics and Chemistry.

The treatment is historical, discoveries are generally described very fully, in some cases even step by step, to enable the reader to see them from the point of view of the time instead of from the present standpoint. Experience over many years has shewn that such a method of treatment is much appreciated by students whose knowledge of the subject is only obtained by casual reading.

The endeavour has been made to bring the subject matters well up to date and as a general rule the practical everyday applications of scientific research have been pointed out.

BIBLIOGRAPHY

Volumes marked thus * are out of print but copies may be obtainable.

The Recent Development of Physical Science, by W. C. D. WHETHAM (Murray 9/–).

The Conduction of Electricity through Gases, by J. J. THOMSON (C.U. Press 25/–).

Radiations from Radioactive Substances, by RUTHERFORD, CHADWICK AND ELLIS (C.U. Press 25/–).

The Interpretation of the Atom, by F. SODDY (Murray 21/–).

Space, Time and Gravitation, by A. S. EDDINGTON (C.U. Press 12/6).

Atomic Theories, by LORING (Methuen 12/6).

Atoms and Rays, by LODGE (Benn 21/–).

The Nature of Things, by BRAGG (Bell 7/6).

The Mechanism of Nature, by ANDRADE (Bell 6/–).

Catalysis in Industrial Chemistry, by HENDERSON (Longmans 9/–).

Coal and its Scientific Uses, by BONE (Longmans 21/–).

Chemistry of the 20th Century, by various writers (Benn 15/–).

The World in Modern Science, by INFELD (Gollancz 5/–).

The Atmosphere, by BERRY (C.U. Press 2/–).

Wireless Telegraphy for Beginners, by BOLTZ (Harrap 3/6).

The Atom, by ANDRADE (Benn's 6d. Library).

Modern Scientific Ideas, by LODGE (Benn's 6d. Library).

Atoms and Electrons, by SULLIVAN (Hodder & Stoughton 2/6).

Talks about Wireless, by LODGE (Cassell 5/–).

The A.B.C. of Relativity, by RUSSELL (Kegan Paul 4/6).

Relativity for All, by DINGLE (Methuen 2/–).

The Theory of Relativity, by EINSTEIN (Methuen 5/–).

**Oil Fuel*, by LEWES (Collins 3/6).

**Coal and what we get from it*, by MELDOLA (S.P.C.K. 2/6).

CHAPTER I

THE DISCONTINUITY OF MATTER

For the purposes of this book matter may be considered to be anything that is capable of being weighed either directly by means of a balance or indirectly by some other method. It may be visible like a piece of lead or invisible like air. It may be in any physical state, gaseous, liquid, or solid, and like water capable of existing in all three states.

When looking at a sheet of glass or of polished steel there appears to be nothing to indicate that it is anything than what it appears to be, an unbroken uniform continuous surface without any crevices or spaces. Even if we examine it more critically with a magnifying glass there is nothing to be seen that suggests any lack of continuity. It is true that if we use a high-power microscope a crystalline or other ordered structure may often be detected but the parts appear to be firmly cemented together and there is no sign of movement. Philosophers of old, such as those of ancient India, held the doctrine that this continuity is only apparent and that in reality all matter is made up of a very large number of very small bits or atoms. Thus the ancient Greek philosopher Democritus writing nearly 2,500 years ago said: "In infinite space is an infinite number of atoms. These atoms are eternal and invisible, absolutely small, so small that their size cannot be diminished. The only things that exist in reality are the atoms in the void."

Throughout the ages the nature of matter was a subject of enquiry and speculation but we had to wait until the

close of the 18th century before a definite foundation was laid on which our present knowledge has been built. By the combined labours of Joseph Priestley, William Scheele and Henry Cavendish during the latter part of that century the composition of the atmosphere and the nature of combustion were discovered, whilst at the close of the century the French chemist Lavoisier gave definiteness to the term "element" which had hitherto been used in a rather loose and unprecise manner. An element was now to be regarded as any substance which could not be reduced to anything simpler by any means then available. Thus from gold nothing but gold could be obtained, from tin nothing but tin, from iron nothing but iron. Gold, tin and iron therefore were to be called "elements." Lavoisier drew up a list of all the known elements, 33 in number, very incomplete as we now know and also in the light of later knowledge incorrect, but a very great advance on anything previously given.

The new century, the 19th, was to see the dawn of a new scientific era. The electric current had been discovered and provided with a new means of attack the chemist was able to add considerably to the list of the elements, and again the nature of matter, particularly elementary matter, became a subject of enquiry. An important step forward was taken in 1808 by John Dalton of Manchester. It was realized that out of the comparatively small number of elements—less than a hundred—all that vast host of substances, animal, vegetable and mineral, composing this and presumably other worlds, were built up by the simple process of combination. By careful experiment and observation the conditions that must be observed before substances would combine had been discovered and stated in general

form as "Laws of Combination." One of these general conditions is known as "The Law of definite proportions," which simply means that if two or more substances combine together to form a new substance they do so in definite, fixed, invariable proportions. For example, if oxygen and hydrogen combine to produce water there must be 8 parts by weight of oxygen to 1 part by weight of hydrogen, and these proportions cannot be varied. If the attempt is made to alter the quantities whatever there is of either element in excess of this proportion is left over when the combination takes place. It is quite true that many elements will combine in more than one set of proportions. But if they do they produce totally different substances and the law still holds good that for each compound there is one, *and only one*, proportion in which the constituent elements will unite. How then does this union take place? Is it like sticking together two pieces of putty or like putting a postage stamp on a letter? If so there is nothing to prevent half a stamp or two stamps or a torn and mutilated stamp being attached. But nothing like this can occur in the combination of two or more elements. A consideration of possible alternatives gave rise to Dalton's *Atomic Hypothesis* which after more than a century of very critical investigation now ranks as one of the foundation stones of Chemistry. According to the Theory, or "Law" as it is now termed, combination occurs not between masses of matter as a whole but between the individual "atoms" of which it is composed. It will be well at this stage for the reader to try to visualize something of the state of things. We shall return to a consideration of the atom in a later chapter, here we are mainly concerned with size and number. All matter, whatever its physical state, is composed of enormous

numbers of separate individual particles, in rapid motion and separated from one another by spaces that are big compared with the sizes of the particles themselves. These are MOLECULES. Whatever properties matter has in the bulk its molecules have. A molecule of water is still water, a molecule of sugar is still sugar. At the time when the theory was formulated no definite idea of the sizes of the molecules was possible, to-day in the light of subsequent investigation we know within certain limits a good deal about their dimensions. Various aids to a visualisation of them have been given by Lord Kelvin, Sir Oliver Lodge and many others, such as that if we imagine a single drop of water magnified to the size of the earth, its molecules would be something between golf balls and cricket balls; or that there are probably as many molecules in a pint of water as there are pints of water in all the oceans of the world; or that in an ordinary pin's head there are about ten million times as many molecules as there are human beings in the world.

Any attempt to get a mental picture of a molecule must fall far short of the reality and microscopic aid is of no use, but at any rate we must realize that it is almost unthinkably minute. And matter is a hurrying, scurrying, vibrating, oscillating crowd of such things! There is one fact that seems to emerge from modern scientific investigation and that is the absence of stagnation, everything is in a state of motion no matter how still it may appear. Probably motion will only cease at the temperature of Absolute Zero which has not yet been reached.

It very soon became evident that small as a molecule is it is composed of something still smaller, the ATOM. Compared with an atom a molecule is big, and here again motion is evident, all the atoms within a molecule being

in rapid motion. A very critical objector might be inclined to say that it is all very well for Science to make such statements, but where is the evidence for them? To such an objection the answer may be made that although positive evidence may be lacking there is an abundance of indirect evidence, quite sufficient to carry conviction. Experimental results are obtained in a very great number of ways that are satisfactorily explained by the Atomic Theory and which cannot be explained in any other way in the light of our present knowledge. Nobody has yet run a tape measure from the earth to the moon but he would be a very cantankerous person who would refuse to accept the astronomical estimate of the distance, especially when eclipses of moon and of sun whose times and duration require the distance for their calculation, are observed to occur in close accordance with estimate. An atom is the smallest portion of an element that can take part in chemical change. This is the old idea of an atom and in spite of changes in our ideas of its nature and structure it is still our definition of it. When elements combine to form compounds the union takes place between the atoms. When Sodium and Chlorine combine to form common salt it is the atoms of Sodium that combine with the atoms of Chlorine. Obviously there cannot be an atom of a compound since it consists of more than one element, so that when two compounds combine there is a reshuffling and a rearrangement of the atoms of which new compounds are the result.

Atoms are the bricks out of which gross matter is built, and the building goes according to plan. During the first half of the 19th century much attention was given to atoms and molecules. Substances were decomposed or broken up into simple component parts, which parts

were subsequently recombined and rearranged, so that by the two processes of "analysis" and "synthesis" a knowledge of the mutual relationships between atoms and molecules was obtained. It soon became evident that the arrangement of the atoms in the molecule was quite as important if not more so than the kinds of atoms employed. By using the same atoms but varying their arrangement in the molecule totally different substances are obtained. If the atoms are all alike we use the term "allotropism" to describe the state of things, if the atoms are not all alike the term used is "isomerism." A good example of allotropism is to be found in connexion with the element Carbon. When the Carbon atoms are arranged in one way we get the substance "lamp black"; if arranged in another way we get "graphite"; whilst arranged in yet a third way we have "diamond." And yet in each of these substances there is nothing but the element carbon, the difference being due to the difference of arrangement of the atoms in the molecules. Organic Chemistry gives us an enormous number of examples of isomerism where similar differences are observed in much more complex molecules. Therefore the properties of a substance depend in part on the *kind* of atoms in its molecules and in part on their *arrangement*. The discovery of this fact was a triumph for the inductive method of reasoning, complete experimental confirmation of which has only been possible in very recent years.

Another property of the atom, its *weight*, was also investigated. Here again the almost inconceivable minuteness of it made actual weighing impossible. Nevertheless experimental work of very great precision combined with inductive reasoning enabled relative weights to be obtained. These weights known as "atomic weights" are expressed in terms of the lightest

element hydrogen. Thus calling the weight of a hydrogen atom 1, the weight of an oxygen atom is nearly 16. For reasons which we cannot consider here it has been found advisable to call the atomic weight of oxygen exactly 16 and that of hydrogen rather more than 1. The atom thus became a reality and was regarded as an indestructible, impenetrable, indivisible entity. Its name implies indivisibility.

Although the atoms of different elements would obviously be different those of the same element were generally supposed to be all alike. We have had to wait for very recent times to be shewn that there are slight differences among them which are now capable of measurement. It must be pointed out however that with the discovery of certain rather rare elements whose properties were unusual the absolute uniformity of the atoms of an element became doubtful.

Another step forward was taken about 1870 by Hittorf, Sir William Crookes and others when investigating the manner in which gases conduct electricity. The best electrical conductors are metals and these differ considerably in their ability to conduct. When so doing they are not materially affected except by being heated—we owe our incandescent lighting and our electric heating to this. Liquids are poor conductors comparatively and are broken up in the process—this property is made use of in electroplating and electrotyping. Gases are even worse conductors than liquids and the problem to be investigated was what happens in their case. As we shall have to refer to this again in a later chapter we may sum up the results somewhat briefly. In order to carry out the experiment the gas is contained in a glass vessel which is connected to an air-pump whereby the pressure can be reduced to any required degree. In the vessel are two metal

terminals, called "electrodes" which are connected to the electric supply, one being called the "anode" and the other the "cathode." At ordinary pressures the electric discharge takes the form of a well-defined flash like a miniature flash of lightning and is accompanied by a sharp snapping sound. As the pressure is reduced by the air-pump the clear definition of the flash and the sharp snap both diminish and after a time the vessel is filled with a luminous glow. With still further reduction of pressure the luminous glow diminishes until eventually when the gas pressure has been reduced to about one-millionth of the original amount there is very little of the glow to be seen but the glass itself of the vessel *at a point opposite the cathode fluoresces vividly.* By having the cathodes in various vessels in different positions and observing that the fluorescence of the glass was always at the place opposite, the conclusion is reached that something is passing *in straight lines* from the cathode. This something which has been called the "cathode stream" has been amplified by an exhaustive series of experiments and it has been shewn that the stream consists of tiny particles travelling at high speed. They can be collected together and made to bombard a target which becomes hot as does an ordinary target bombarded with ordinary bullets. Attempts to ascertain their nature were made but this was difficult as they were locked up within the glass vessel and all attempts to get into closer contact with them met with failure. It was however ascertained beyond reasonable doubt that both molecules and atoms were much too large and massive to account for the observed behaviour of these new "bullets." As nothing was known smaller than an atom the term "radiant matter" was given to the matter in the cathode stream by Sir William Crookes in 1874. He suggested that it

might constitute a sort of borderland between matter and energy. The outstanding and highly important result of the investigation was the discovery that small as an atom is something much smaller exists.

Another step forward was taken in 1898 when Madame Curie discovered Radium. An account of the discovery will be found in Chapter VI but certain properties of the new and extraordinary element must be considered here. As its name implies one of its striking properties is that of emitting "rays." The nature of these and the mode of their emission were for several years a great puzzle for the scientific world. Investigators were at work all over the world trying to find a satisfactory answer to the riddle, but we had to wait until 1903 before an acceptable answer could be found largely owing to the brilliant work of Professor Lord Rutherford of Cambridge and Professor Soddy of Oxford. The conclusion reached is truly amazing. For some unknown reason and quite without any external stimulus atoms of Radium explode and eject minute "bullets" among which are to be found those of the cathode stream. They are travelling at a fearful pace compared with which the speed of a rifle bullet is a mere leisurely stroll and many of the curious properties of Radium are due to their impact on other bodies. The large army of investigators and the ingenuity and precision of their methods have disclosed the nature of these bullets. They are almost $\frac{1}{2,000}$ the weight of the lightest known atom—that of hydrogen and are invariably associated with a charge of electricity, hence the name ELECTRON has been given to them. When Crookes and his co-workers were speculating on the nature of the "radiant matter" which had been obtained by the expenditure of thousands of volts of electricity they were prevented from proceeding further because it was

contained in a glass vessel which prevented closer approach. The discovery of Radium and the radio-active minerals from which it is obtained, which at all times are freely emitting electrons and have been doing so during long geological ages, shews that all the time they were surrounded by hosts of the very things they were trying to get at.

We now know that an electron is perhaps the smallest thing in the Universe and the most wonderful. We are dependent on it in a great variety of different ways and we are, probably unknowingly, constantly making use of it. Electrons are present in rapid orderly motion in all atoms. In some of the atoms of the sun electrons are moving in a particular manner with the result that a ray of light darts across the intervening 93 million miles and in about eight minutes reaches the earth. A large electric power station distributes electric current over a district providing a source of light, heat, power or traction because electrons are moving in a particular way in the coils of wire and cables of the station machinery. In the oscillation-valve of a wireless receiver there are myriads of electrons swarming from the lighted filament like a vast swarm of bees and so guided and controlled in their flight by the grid and plate of the valve that sounds in the broadcasting studio or wherever a microphone is installed are reproduced with a faithfulness that is still a source of wonder to many wireless listeners.

Although modern views about the atom will be considered in greater detail in another chapter we must mention here that there is still another constituent of the atom which is known as a "PROTON." This is also very small in size but much heavier than an electron and it too is electrified but in the opposite sense to an electron, viz., positively and equally in amount. A negatively electrified

electron and a positively electrified proton would therefore together produce an electrically neutral combination.

It is well known that matter in the bulk can be compressed, especially in the case of gases. Robert Boyle in the 17th century studied the effects of pressure on air and gave us the Law that is known by his name. As we compress a gas its volume diminishes proportionately and its temperature rises. In the case of some gases pressure alone will convert it into a liquid, but as a rule both pressure and cold are required for liquefaction. By the suitable variation of these gases can also be solidified. We said above that increase of pressure produces a rise of temperature. This is what would be expected if the heating of a body simply means increasing the rapidity of the motion of its molecules, for as they are squeezed more closely together their collisions with one another would become more frequent. The converse is strictly true; as a gas is rarefied its temperature falls, rapid evaporation produces a temperature drop. We all know the feeling of cold when a little ether or spirit is poured on the hand, its very rapid evaporation produces at once a sense of cold. The rapid evaporation from the wet outer surface of a porous earthenware vessel of water may freeze some of the water it may contain. In dry weather a wet bulb thermometer shews a lower temperature than a dry one. Our weather, clouds, rain, hail are largely affected by changes in pressure of the air at various high levels. To take a familiar example water may, owing to differences of pressure or of temperature be either water vapour, liquid water or ice, but it never ceases to be "water"; that is if we could examine a single molecule of it it would be the same whatever its state. As water vapour its molecules are widely separated and moving about freely with little or no

restriction. As liquid water the same molecules would be much closer together, probably several bunched together to form more complicated groups and much less free to move; as ice they would be still closer together probably in much more complex groupings and still less free in movement. But all the time the molecule is still the same in its simplest form. How far can compression go on? Can we squeeze the molecules into actual contact, then still further squeeze the atoms within the molecules into contact; further still can we then by external agency force the electrons and protons into contact? The answer to this is very decidedly "No." Whatever pressure is applied, whatever degree of cold, whatever physical force at present available may be used they are still not in contact. Whether this is possible in other conditions or other Worlds is a question difficult to answer. There are some among our foremost astronomers who maintain that only in this way can the behaviour of certain celestial bodies be accounted for. If such a thing were possible we should be able to pack several tons of matter within the limits of an ordinary match box.

We may summarize somewhat as follows: However *continuous* matter may seem to the senses, even with instrumental assistance, it is really *discontinuous* or made up of a very large number of separate particles called *molecules* which are in rapid motion with relatively plenty of room to move. We can vary the rate of movement; the hotter we make a body the more rapidly do its molecules move, but we cannot bring them absolutely to rest by any process of cooling. All molecules consist of *atoms* in orderly array, also in motion; they are the chemical units, nothing smaller than an atom enters into chemical union to form a molecule. They are the

" bricks " of which all things are built and the manner of their arrangement in the molecule is quite as important as their own nature. Allotropism and isomerism are examples of differences of grouping of atoms within molecules.

Even atoms, small as they are, contain smaller things called electrons which are also in rapid orderly motion, the weight of an electron being about $\frac{1}{2,000}$ that of an atom of hydrogen. All electrons, whatever their source, appear to be alike and are always associated with a charge of negative electricity. They give rise by their motions to many well known everyday phenomena such as electric currents, light, magnetism, etc. The atom also contains something else which has been named " proton," minute in size but almost as heavy as the atom. All these things, molecules, atoms, electrons, protons, that together constitute matter as we come across it in the bulk are not in contact, nor can we by any means of mechanical pressure at our command bring them into contact; if we could we should be able to pack tons of matter within the compass of an ordinary match box.

CHAPTER II

ELECTRICITY: ITS PRODUCTION AND USES

THERE is a natural desire, very generally expressed, to ask the question "What is electricity?" To reply that nobody knows seems to give little satisfaction. When on every hand, even in remote country villages, it is in everyday use, for modern day scientists to have to admit ignorance does appear to be rather absurd. Yet an honest answer must be that its true nature is unknown. Is it matter? If the test for matter is to be the one expressed in the last chapter, viz., weighability, the reply must be "No." But that test may not be a really critical one and it is very difficult to decide what test can be used that is free from uncertainty. If it is matter it must be "atomic," for all matter is atomic. Well, it *is* atomic, that is to say it appears to exist in small parcels like matter, nicely packed up and tightly sealed so that we must either take a whole parcel or none. We cannot unpack it and use a portion of it. In this respect therefore it does resemble matter and it is quite reasonable to speak of atoms of electricity just as we refer to atoms of matter. Moreover the atom of electricity is just that amount that is always associated with the tiniest known portion of matter—the electron. There are some who would go so far as to say that the electron *is* the atom of electricity and nothing else, in which case matter and electricity are one and the same thing. This is not a mere empty assertion, there is a good deal of experimental evidence that can be called in support of it. So long as we consider things in the bulk, as we usually meet them in everyday life matter and electricity seem to be quite

distinct but when we examine it in its minutest forms—atoms and electrons—it is extremely difficult to decide which is matter and which is electricity.

There is no useful purpose to be served by dwelling on this aspect of the subject any further for the present, so we will now consider some of the modes of production of electricity using the conventional expressions of the day in describing its properties and behaviour. Although we generally come across it in the form of a " current " and to most people electricity is an electric current and nothing else, we propose to defer for a little while the consideration of currents and see how electricity behaves when stationary.

The fact that certain substances when rubbed acquired a new property was known as a curiosity thousands of years ago to the ancient Greeks, and because it was observed to be very noticeable when the substance rubbed was amber, the word " electricity " is used to describe the acquired property, from the Greek " electron," meaning " amber." The new property was that of attracting light objects such as bits of silk, feather or ordinary dust. Eventually it was found that if proper precautions are taken it does not matter what is rubbed nor what is the rubber. The effect is very marked if glass is rubbed with silk or ebonite with fur, care being taken to have everything dry and preferably warm. The substance is now said to be " electrified," or electrically " charged," moreover the " charge " appears to be confined to the surface and easily removed by passing the hand over it. There is nothing visible to indicate the presence of the electric charge, no change of any physical quality of the charged body and yet there is something that was not observable before, viz., the power of attraction of light objects. Given certain conditions, the power

can be retained indefinitely. Another curious fact is that the charge on glass rubbed with silk is not the same as that on ebonite rubbed with fur. It is the same in its effect on uncharged bodies but in their behaviour towards each other the charges behave in a different manner. In order to distinguish the charges the one on glass rubbed with silk is called "positive" or "+" and the one on ebonite rubbed with fur "negative" or "−." Let it be clearly understood these terms are purely conventional and any other convenient terms could be substituted for them. There thus appear to be two kinds of electrification which might easily be interpreted as implying two kinds of *electricity*. In the past this view was very generally accepted and even to-day we use the language of two kinds: we speak of a body being charged with positive or negative electricity. The tendency in recent years has been to regard electricity as of one kind only, the negative kind, the electron being its atom, but certain results obtained at the Cavendish Laboratory, Cambridge, in 1932 and 1933, seem to indicate that there is a positive electron also. If this turns out to be correct there are definitely two kinds of electricity, positive and negative, discontinuous as ordinary matter is, the ultimate particle being the positive electron and the negative electron, the latter being much more easy of isolation than the former.

A brief review of the facts is that bodies generally are electrically neutral, i.e., shew no signs of electrification: by various simple physical means, such as rubbing, heating, fracture, they become electrified: both kinds of electrification always appear at the same time and in the same amount, if the rubbed body is + the rubber is −: when the two charges are brought together, neutralisation results and all signs of electrification disappear.

Although it was known that electricity would pass from one body to another and that some substances would allow it to pass more freely than others there was no known means of producing a steady continuous flow until the beginning of the 19th century. The credit for the discovery of the electric current is usually given to Galvani, an Italian physician, who made some very important observations about 1790. The story goes that a medical student called his attention to the curious behaviour of a frog's leg lying on a copper dish when touched with a steel knife. Owing to his knowledge that a frog's leg would twitch under a discharge from an electric machine, Galvani attributed the phenomenon to some supply of electricity possessed by the frog similar to that of the electric eel. A contemporary of his, Professor Volta, of Pavia, however, proved conclusively, about 1804, that it was not the frog but the copper of the dish and the steel of the knife that were responsible for the electricity. One of his experiments should be recorded. Taking a number of discs of copper and zinc, he arranged them in pairs, a copper and a zinc disc forming a pair. Making a pile of these pairs like a pile of coins and separating one pair from another by a pad of felt moistened with brine, he showed that a tiny electric spark or a slight shock could be perceived when contact was made between the copper disc at one end of the pile and the zinc disc at the other end. Further research shewed that the copper disc seemed to be electrified positively and the zinc disc negatively, so that by maintaining contact between the two a continuous flow of electricity could be obtained. The amount of current was very minute, but the discovery was a most important one. It is now known that when any two dissimilar metals and a few non-metals are linked together by means of an acid or an alkali an electric

current can be obtained. Volta's discovery is the basis of the many electric batteries in use to-day, often associated with the names of their designers, such as Bunsen's, Daniell's, Leclanché's. They all consist of a liquid called an electrolyte, that will combine chemically with one of the metal plates, a second plate of a substance that remains unchanged by the electrolyte, all enclosed in a container called a " cell," a number of cells suitably joined together being known as a " battery." The best known battery is the Leclanché, used for electric bells and as a " dry " battery for flash lamps and many other purposes. In the latter case the electrolyte is made into a paste with some absorbent so as to prevent spilling. Both Galvani's and Volta's names have been perpetuated, the former by referring to electric currents as " Galvanism," or " Galvanic electricity," and the latter by naming one of the electrical units the " Volt." A useful picture of a battery may be obtained by likening it to a pump constantly raising water from a pond to a tank from which there is an outlet pipe leading back to the pond.

During the next thirty years three important discoveries were made that may be regarded as landmarks in the history of electricity. These were ELECTRO-MAGNETISM discovered by Oersted in 1819 and more fully investigated by Ampère in 1821, the laws of CONDUCTION by Ohm in 1827, and ELECTROMAGNETIC INDUCTION by Michael Faraday in 1831. Let us consider each of these in detail. Oersted, at Copenhagen, happened to bring a magnetic compass needle near a wire along which an electric current was passing, and noticed that instead of pointing north and south in the usual way, it pointed east and west. On reversing the current the compass needle also reversed there was obviously some connexion between magnetism

and electricity. It was well known that magnets would attract iron and would attract or repel other magnets according as dissimilar or similar poles were brought near to each other. Action at a distance is unthinkable. The earth, the sun, the moon, all the planets, act on each other although separated by great distances, yet no one for a moment imagines the absence of some connecting link. And so in the neighbourhood of a magnet within its sphere of influence on a piece of iron or another magnet there is an abnormal state of things which is expressed by the term MAGNETIC FIELD. Oersted's experiment shewed that near a wire conveying an electric current there also seemed to be a similar sort of FIELD. In 1821, André Marie Ampère in Paris, heard of Oersted's experiment and commenced a series of investigations, which caused Clerk Maxwell to refer to him as the Newton of electricity. He shewed that there is a *magnetic* field round every live electric wire; that such wires would attract or repel each other by amounts to which he gave precise mathematical expression; that passing a current round a piece of iron converted it into a magnet; that the coil of wire alone without its iron core also behaved as a magnet.

Ampère's "Rule" for ascertaining the direction of deflection of a compass needle, often called the Mannikin Rule is as follows :—

"Imagine a tiny mannikin swimming in the wire in the direction the electric current is flowing and always keeping his face turned towards the compass needle: then the North Pole will always turn towards his left hand."

Among the many applications of Ampère's investigations may be mentioned :—

(*a*) Electric bells, fire alarms, burglar alarms and other suchlike signal devices:

(*b*) Telegraph instruments of several types:

(*c*) Safety switches for automatically stopping machinery, trains and tramcars:

(*d*) Magnetic cranes for moving large masses of iron and steel in ironworks and for loading scrap metal into trucks:

(*e*) Magnetic locks for miners' safety lamps to prevent lamps being opened in dangerous mines.

(*f*) Telephones and wireless loud speakers.

The applications of the electro magnet are so very numerous that many others will readily occur to the reader.

In 1881, the International Congress of Electricians, held at Paris, decided to honour Ampère by calling the unit of electric current by his name, therefore to-day we speak of a current of so many ampères.

The second great landmark was the discovery of the laws of conduction in 1827, by George Simon Ohm. Working at Cologne, he found that just as heat was transmitted much more readily by some substances than by others, so also substances differed considerably in their ability to conduct electricity. There is no such thing as a perfect conductor, all resist in varying degrees the passage of electricity through them and in so doing fritter away some of the electricity, with the production in every case of a definite quantity of heat. Generally speaking, this heat is unwanted and represents waste, but it can be, and is, made use of in heaters and in electric light. Ohm found that the resistance varies directly with the length of the conductor, and inversely as the cross section or as the square of the diameter—with

circular conductors, thus with two wires of the same material and length, but one having three times the thickness of the other, the *thinner* wire will have *nine times* the resistance of the thicker one. This fact makes it a matter of great importance that in order to avoid loss of current conducting wires should be as thick as possible. The difference in conducting power owing to difference of material, *conductivity* as it is termed, is illustrated in the following table :—

Calling the conductivity of copper 100, the conductivities of other metals are :—

Silver .	105	Platinum .	17
Gold .	76	Iron .	10
Aluminium	54	Lead .	8

Ohm's work was of the greatest importance in that he gave precision where before it was lacking ; he provided a definite relationship between the amount of current, the force driving the current along and the resistance of the conductor. This he expressed in "Ohm's Law"

$$C = \frac{E}{R}$$

Where C is the amount of current in ampères, E is the electromotive force in volts and R is the total resistance of the circuit in ohms. His name is perpetuated by calling the unit of resistance the "Ohm." The ohm is the resistance of a column of mercury 106·3 centimetres long at 0° Centigrade and weighing 14·45 grammes.

By his contemporaries Ohm's work was either derided or ignored. He found it necessary to resign his position as teacher of physics at Cologne, the Minister of Education having said that anyone who preached such heresies was unfit to teach the young. After fourteen years, however, the importance of his discoveries was recognized

and the Royal Society of England awarded him its most coveted distinction, the Copley Medal.

Non-technically minded people often find a difficulty in understanding electrical measurements, so at this point a simple consideration of a few common measurements may be found useful. Although we must not stress the analogy too far, a good deal of help can be obtained by comparing an electric current with water flowing in a pipe. On the one hand there is the water—as water, on the other hand there is the electricity—as electricity—the thing itself. We can speak of and measure a definite quantity of water, a gallon, a cubic foot or a pound, using any unit we please: similarly we can speak of and measure a quantity of electricity using as a unit a "Coulomb" which is the amount of electricity which will deposit 0·001118 gramme of silver from a silver solution. Again, by allowing water from our pipe to run into a measure and noting the time we should know the yield of water, so many gallons or pounds per minute: so also we could find how many coulombs of electricity are delivered in a given time. *1 coulomb of electricity in 1 second is 1 ampère of current.* Again, we know that water will not flow unless there is some power driving it along, often expressed in terms of the height from which it starts—the "head" of water, so also electricity needs a driving force to push it along: this is the "Electromotive Force" or "E.M.F." and is measured in "Volts." We might have a very small quantity of water with a very great pressure and yet it might not be capable of doing much work; on the other hand a large quantity flowing from a small height, like a river over a weir, might be capable of turning a water-wheel. Therefore, in order to know the available energy we must know both quantity and pressure. In the

electrical analogy we must know both the ampères and the volts, so we multiply them together and express the result in "Watts." Thus 200 volts and 5 ampères give 1,000 watts. This is a measure of the energy of the current. Lamps, motors, radiators, &c., are rated in watts, thus we have 50-watt lamps, 1 kilowatt radiators, &c. (1 kilowatt = 1,000 watts). Finally, if time is also considered, the product of watts and hours is called "watt-hours," and 1,000 watt-hours is 1 Unit. Thus a 50-watt lamp used for 20 hours consumes 1,000 watt-hours, or 1 Unit of current.

The third great landmark already mentioned was the discovery by Michael Faraday, in 1831, of Electro-magnetic Induction. The story of Faraday's life is an interesting one, but this is not the place to record it. Suffice it to say that from humble beginnings, with no educational advantages, by hard work with singleness of purpose, he rose to a position of eminence in science that has been attained by few. He might have been wealthy if he had abandoned his pursuit of Pure Science, but he made his choice, and by so doing enriched Science to an almost incalculable degree and died a poor man.

Succeeding Sir Humphrey Davy as Director of the Royal Institution, London, at a time when the discoveries of Oersted and Ampère were arousing interest in the scientific world, he decided to investigate more closely the connexion between Magnetism and Electricity. His researches occupied many years, culminating in 1831, in the discovery of Electromagnetic Induction, with which his name will ever be intimately associated. Briefly stated, the discovery may be thus expressed ! If two coils of wire, A and B, are near each other, and through A a current is passing, any change in the strength or direction of the current, or the stopping or starting of it, or any

change in the relative positions of the coils will cause a current to flow in coil B *whilst the change is taking place.* So long as the current in A is invariable or the relative positions of A and B are unchanged nothing happens. Coil A can be replaced by a magnet with the same result in coil B. The current thus produced in coil B is called an "Induced" current and the Principle is termed "Electromagnetic Induction." By this discovery a new era in the history of Electricity was introduced, that of the production of electric current by mechanical means. The large-scale production of current was now possible. All that was required was a strong magnetic field with coils of wire moving in such a way that the number of lines of magnetic force passing through them is constantly changing or, as it is termed, so that there is a constant change in the "Magnetic Flux." Whilst this is going on an electric current will flow in the coil. In a dynamo, or generator, as it is usually called, the strong magnetic field is obtained by means of a number of electromagnets suitably arranged either in a fixed frame or on the circumference of a wheel. The coils of wire are arranged either on the circumference of a wheel, in which case it is called an "armature," or in a fixed frame. Thus sometimes the magnets are fixed and the coils rotate and sometimes the coils are fixed and the magnets rotate. In either case there is "relative motion" between magnets and coils.

When the current flows in one direction only like water in a river, it is called a "Direct Current" or "D.C.", when it flows backwards and forwards, changing like a swinging pendulum it is called "Alternating Current" or "A.C." In a large power station energy is supplied to engines of the turbine type by water power when that is available, by burning coal or other fuel, by making use of waste materials such as town refuse, waste gases from

collieries and industrial works and by burning in special furnaces low grade fuel when that can be done with little cost for its transportation. Although we speak of "producing" the electricity, we are really only rendering available something which existed before but was not in such a state that we could make use of it. When water is pumped from a lake into a reservoir at a higher level, energy is available from it when it is allowed to flow back to the lake. Somewhat similarly, when by means of the machinery in a power station a difference of electrical level, or a difference of "potential" as it is termed, is produced energy is available as the electricity flows back and the original conditions are restored. A ton of coal contains a certain definite amount of energy, some of which can be made of use in various ways, the production of electric current being one. Some of the energy of the coal is converted into electrical energy and in the conversion there is, as is usual, loss. There is loss due to heat losses in the production of steam, to friction of moving parts of machinery, to inertia, to transmission of the electricity from the power station to the place where it is required and other causes. Thus the energy available for use as electric current is only a small proportion of the total energy contained potentially in the coal—or other source of power. For the successful distribution of electricity on a commercial scale a very careful watch has to be kept on possible causes of loss so as to cut them down to their lowest limit; one very serious item of cost being that of transmission of the current.

Mention has already been made that there are two kinds of current, direct and alternating. At the moment of production, all currents obtained by mechanical means are alternating. In a D.C. generator the alternating currents are "commuted" and rendered direct: in an

A.C. generator they are left alternating. For many purposes, e.g., lighting and heating, it does not matter which kind is used provided the alternations are sufficiently rapid. If there are fifty alternations in a second there is no observable flicker in an incandescent lamp, whereas if there were only five alternations the light would flicker badly. Hence it has been decided in this country that 50 alternations per second, or "50 cycles" shall be the frequency of the current for public service. Formerly the various companies supplying current used various frequencies to suit their own particular needs. With the passing of the Electricity Act all this has been changed. It has been decided that instead of there being a large number of power stations scattered over the country, many of them serving only a small area, and supplying current of all sorts of frequencies, there shall be a much smaller number of larger power stations suitably distributed, capable of supplying current under more economical conditions, producing alternating current of 50 cycles and linked together in the so-called "grid system," so that they can be mutually helpful when required. As the distances of transmission under this National Scheme are much greater than formerly the question of transmission losses has been an important one. And it is here that the advantages of alternating current have become evident. We have seen that a certain amount of the current is wasted in overcoming the resistance of the conducting wires, in other words a certain number of the volts will always be lost in this way. If the voltage of the current is high, the proportionate loss of the transmission volts will be less than if it is low. A small boy, whose whole wealth is one shilling, would find the loss of sixpence a much more serious matter than a wealthy man with thousands of pounds. If, therefore, the current can be

at many thousands of volts the proportionate transmission losses will be very much less than if transmitted at the previously usual few hundreds of volts. But high-voltage currents are dangerous and could not be allowed for ordinary domestic supply and workshop use, therefore if they are to be transmitted at high-voltage there must be some means of cutting them down to safe dimensions before they come to be handled by all and sundry.

The cutting-down of the voltage, or "transformation" as it is called, can only be done in the case of direct currents by means of machinery, and this would completely neutralize any other possible advantage. With alternating current the transformation is simple and is done by appliances known at "static transformers," in which use is made of the principle of electro magnetic induction discovered by Faraday. It will be remembered that if there are two coils of wire, A in which a current is flowing and called the "primary," and B called the "secondary," in which there is no current, any change in A will "induce" a current in B which alternates rhythmically with the changes in A. Moreover, whatever the relationship between the number of turns of wire in the two coils the same relationship will exist between the voltages of the currents. Thus, if the secondary has 10 times as many turns as the primary, we have a "step-up" transformer with 10 times as many volts in the secondary as in the primary. If the reverse were the case we should have a "step-down" transformer with the voltage in the secondary only $\frac{1}{10}$ that of the primary. We are here dealing only with the mere outline of the principle; in practice there are many points that require very careful consideration and attention. It may seem at first sight that if by such a simple device a few hundreds of volts can be transformed up to many thousands we are getting

something for nothing. This is not true; every physical transformation has to be paid for. The total electric energy is the watts, i.e., volts × ampères, and if the volts are transformed *up* the ampères are transformed *down* in the same ratio, therefore the total Energy remains the same. A given sum of money would convey a large party of travellers a short distance, or a small party a greater distance. The actual electrical energy is the volts multiplied by the ampères and we are able to arrange their relative values to suit our requirements.

The following may be taken as a typical example of modern practice in England. At a large power station huge generators produce current at 5,500 volts, which is transformed up to 33,000 volts by large transformers, to be again transformed up to 132,000 volts. This *high-tension* current is conveyed, by cables supported by latticed pylons equipped with massive insulators to prevent leakage, across open country. At suitable points step-down transformers are provided to bring the current down to the few hundred volts that may be safely used for ordinary everyday purposes. One very important point in the reduction of cost of production is the "equalisation of load." At night, when current is needed for lighting, there is a big demand. If a similar demand can be obtained in the daytime, for factories, workshop, and domestic purposes and therefore a more uniform demand established throughout the 24 hours, production costs are materially reduced.

Some applications of electricity.

(*a*) *Lighting.* The underlying principle of all systems of electric lighting is that every conductor is heated when a current passes through it. If the conductor is a thin metal wire we have the "filament lamp" or ordinary

incandescent lamp; if it is a gas we have the mercury lamp or the Neon lamp.

A word of caution is necessary in connexion with the use of electrical appliances of all kinds. The quantity of electricity—the *ampères*—is being driven along by the electrical pressure or potential—the *volts*—and each piece of apparatus, the lamp, motor, heater, vacuum cleaner, or whatever it may be, is constructed by its manufacturer to work with a certain number of volts. If a steam boiler designed for 100 lbs. steam pressure had the steam raised to a pressure of 200 lbs., there would probably be an explosion. Similarly, if an electrical appliance designed to work with 100 volts is used with 200 volts serious damage will result.

The filament incandescent lamp contains a thin wire made of the metal *tungsten* which has a high resistance to the current and therefore readily becomes heated when a current is passed through it, quickly reaching a state of brilliant incandescence. Before the discovery of the gas *argon* the highest stage of brilliance could not be reached because if the air were left in the bulb it would combine with the tungsten and the filament would be destroyed. If the air were pumped out of the bulb the heated filament would volatilize at a very high temperature and so the filament would disintegrate. Argon being an inert gas with no affinity for the tungsten can be introduced into the bulb and the filament can now be raised to the temperature of maximum incandescence. A lamp so constructed is known as a "gas-filled" lamp.

For safety purposes electric circuits are provided with *fuses* or *cut-outs*. These are short lengths—a few inches only—of an alloy that will melt at a temperature below the danger level, introduced at suitable points in the circuits. If for any reason too much current flows the

temperature of the fuse rises to the melting point and so the circuit is broken. Replacing a burnt-out fuse with a piece of ordinary wire in an emergency is a frequent cause of fire or other accident.

(*b*) *Heating.* The production of heat for radiators, cookers, laundry irons, &c., depends on the same principle that the resistance of a bad conductor converts some of the current into heat. A *heating element* consisting of small poor conducting material is suitably placed in the walls of the cooker or other appliance, and by its resistance produces the necessary rise of temperature. In some types of electric furnace for industrial purposes the heating element is wound round the outside of the body of the furnace and then surrounded with either a water jacket or a heat-resisting cover so as to avoid loss of heat. Very high temperatures can be obtained by using the *electric arc*, and furnaces of this kind are employed for smelting certain refractory metals and for the manufacture of Calcium Carbide and Carborundum. The former, a compound of Calcium and Carbon, is largely used for the production of Acetylene ; the latter, a compound of Silicon and Carbon, is next to the diamond in hardness and is extremely useful as an abrasive for grinding and polishing purposes. Another use of electric heating is for *welding.* The metal surfaces to be joined are suitably prepared, pressed into contact and an electrical current passed, when the high resistance at the contact surface causes a local high temperature of sufficient amount to produce a perfect union.

(*c*) *Electrolysis.* When an electric current is passed through a metallic solution the metal is deposited on any conducting cathode. Using a suitable solution of silver, articles made of some base metal may be hung from the cathode, and when a current is passed a deposit of silver

adheres to them ; in this way electro-plating is done. In "*electrotyping*" an impression of some article to be copied is made in some plastic material. This is then coated with a conducting substance such as graphite and the required metal electro-deposited on it to any desired amount. When the mould is removed, an exact copy is left. In this way a facsimile in copper of the markings of a crocodile skin can be obtained and used to impress ordinary leather or cardboard for imitation crocodile skin articles, or copies of coins and medals can be produced. In chromium plating a solution of nickel is first used to obtain an electro-deposit of nickel and on this the chromium is electro-deposited from a chromium solution. When a solution of brine is electrolysed the sodium produced reacts chemically with the water and caustic soda is obtained along with chlorine ; these can either be isolated separately or allowed to combine and produce chlorinated solutions. By fusing common salt and electrolysing the melt sodium metal and chlorine can be obtained.

Metals obtained by ordinary smelting purposes are seldom pure. Electrolysis is often used to obtain the pure metal from impure ingots. In this way especially copper, silver and gold are obtained in pure state from impure bars.

(*d*) *Motors*. The electric motor enables electrical energy to be converted into mechanical energy in a convenient manner. For traction purposes the current is supplied by an overhead conductor or by a " live " rail on the ground, the circuit being completed through the wheels and rails. In workshops the noisy, dusty system of belts and pulleys is replaced by an electric supply to motors for each machine or group of machines. Motors for domestic purposes have many applications, among which may be mentioned

vacuum cleaners, fans, sewing machines, and refrigerators. Practically all refrigerators depend on the fact that when a liquid rapidly evaporates cooling results. Every liquid, before it can be converted into vapour must have a certain amount of heat supplied to it. Everyone knows that heat must be supplied to water before it can become water-vapour. There are certain gases which can easily be liquefied by pressure, e.g. ammonia, sulphur dioxide and cymogene—a derivative of petroleum. A small motor working a compression pump liquefies the gas in a stout steel container. Connected with this is a system of pipes round the refrigeration chamber. The liquefied gas evaporates into the pipes absorbing the necessary heat for the purpose from the refrigerating chamber, thus producing the required low temperature. The gas passes on into the container to be recompressed and liquefied again. By means of thermostats the operation becomes automatic and any desired temperature can be maintained.

CHAPTER III

RADIO-TELEGRAPHY AND -TELEPHONY

INSTANCES of an effect produced by a cause which is apparently quite detached, without any obvious points of contact are quite common in our ordinary experience, so common indeed that they rarely call for comment. That light comes from the sun many millions of miles away across an apparently empty space is a commonplace of knowledge, but that it takes time over the journey is often forgotten. It is not easy to realize that we see an object not as it *is* but as it *was* an appreciable interval of time ago. For instance we see the sun as it was about eight minutes ago. We can find many examples of apparent "Action at a distance," such as the attraction between the Earth and the Moon, or between a magnet and a piece of iron, and in every case the mind is not satisfied with the idea of an action at a distance without any connecting link between cause and effect. Through the centuries many great minds have grappled with the questions "What is light" and "How does it travel?" Careful consideration of the properties of light has led to the conclusion that as far as our knowledge goes there are only two possible explanations—either it is the result of waves or of a stream of minute particles. That is, a source of light acts like a stone dropped into a pond and causing ripples to travel through the water, or like a machine gun firing a hail of bullets. The first is called the "Wave theory," the second is the "Corpuscular" theory. Eventually it was generally agreed that the Wave theory gave the most satisfactory explanation of optical phenomena, although certain

other properties of light were not fully explained by it. Since a wave requires a medium in which vibrations can occur, such a medium has been supposed to pervade space and the name "THE ETHER" has been given to it. There is no connexion between it and the well-known chemical liquid which has the same name. To prevent confusion, the all-pervading ether is sometimes spelt "AETHER." Its properties are so extraordinary and difficult to picture that at this stage attempts to visualize it will lead to confusion. Better, I think, to accept it, state its main properties for the subject in consideration and pass on. The properties that concern us are the following:

(*a*) All ether waves travel at the same speed, viz., 186,000 miles—or 300,000,000 metres—per second.

(*b*) Waves of different lengths—wave intervals would perhaps be a better term—produce different effects such as *heat*, *light*, *X-rays*, &c.

(*c*) Waves that can be detected by the eye—light waves—are very short; the longest being only $\frac{1}{30,000}$ inch long and the shortest half that length.

In 1865, James Clerk Maxwell of Cambridge announced that in his opinion there ought to be ether waves very much longer than those already known and that it was almost certain that they would have electrical properties. They would differ from light as Atlantic rollers differ from ripples on a pond. Many years had to elapse before Maxwell's forecast was verified, although investigations were going on in many parts of the world. It is probably true that more than once a curious and unexplainable electrical effect was observed and recorded but the experimenter failed to connect the occurrence with Maxwell's predicted long ether waves. It was

left for Henry Hertz, a young German scientist, to make the long sought for discovery in 1887. The difficulty had been, not in the production of the waves, that was easy, but in the detection of them, and Hertz' detector though simple, was not very sensitive. Once the principle had been ascertained a host of experimenters set to work and very quickly other and more delicate means of detection were discovered. It is worthy of note, however, that for several years the interest lay in detection of the waves, in their measurement, in the proof that they were of the same kind as waves of light, differing from them in degree only. Their application to telegraphy or telephony was still to come. Even seven years after Hertz' discovery and after his death, at a Memorial lecture given in London by Sir Oliver Lodge, in the presence of many world-famous scientists, it was the production, detection and demonstration of the properties of the waves, now called "HERTZIAN" waves, that received attention rather than their application to signalling.

The problem of dispensing with line wires for telegraphy had received a good deal of attention, especially over short distances. In severe storms of snow and wind telegraph poles and wires are thrown down, cutting off connexion for inconvenient periods. At such times also communication between the mainland and outlying islands becomes difficult and stormy seas cause damage to submarine cables. Obviously, therefore, any system of signalling that can dispense with the use of cables and poles is bound to possess an advantage.

Long before the discovery of Hertzian waves attempts were made to dispense with wires. Conduction through the ground and through water were both tried, making use of the conducting power of the earth and of water, especially sea water, but the disadvantages were too great

for the system to be anything but a temporary stop gap at times of emergency and over short distances. Results were too uncertain to be of really permanent value. Another plan that gave greater promise was the use of electromagnetic induction. When an electric current oscillates in a circuit it can induce a current in a similar circuit parallel to it and at some distance from it. This plan was put into operation between the mainland and outlying islands with some success and was of value during a breakdown of direct communication but was uneconomical as a permanent establishment.

With the discovery of Hertzian waves a new chapter was opened in the history of signalling, the name "Marconi" becoming prominent in further developments. Although he was by no means the first in the field of investigation he has done much to bring radio-communication to its present state of efficiency. His interest in the subject was aroused through the influence of Prof. Rhigi, of Bologna, where he was then living. He carried out a number of experiments in the grounds of his father's estate there, where he made an important discovery, that of connecting part of the apparatus to the earth—"earthing it." In 1895, he came to England and succeeded in interesting Sir Wm. Preece, chief electrician to the Post Office, in the subject. Together they carried out a number of experiments in Somersetshire, on Salisbury Plain, at Poole and in the Isle of Wight, steadily increasing the signalling distance and developing the apparatus employed. This took several years and the progress was most encouraging. In 1898, reports of a regatta at Kingstown were transmitted 20 miles: in the same year communication was established between the S. Foreland lighthouse and the E. Goodwin lightship, with the result that in 1899 the lightship was able to

ask for assistance after collision with a steamer. In 1899, too, the Channel was bridged and messages passed between Queen Alexandra and the Mayor of Boulogne. By 1901 a large wireless station was established at Poldhu, near the Lizard, which was able to keep up communication with Alum Bay in the Isle of Wight, a distance of 200 miles. By this time Marconi was ambitious enough to attempt to signal across the Atlantic, a feat which he achieved in December, 1901.

In ordinary line telegraphy three things are required; (*a*) a system of electric currents under the control of the operator, that is, capable of being stopped or started or reversed at will; (*b*) some piece of apparatus at the receiving end that will do something when an electric current passes through it, and (*c*) a connecting link. It doesn't matter very much what the receiver does so long as it is readily recognisable. It might be a lamp that would light up, or a bell that would ring, or a magnetic needle that would swing to and fro, or a printer, or a telephone. All these are used in some form or other. The connecting link is the line wire overhead on telegraph poles or underground in cables. In radio-telegraphy the same three things are required. If a visit is paid to a broadcasting station there can be seen complicated electric circuits and many forms of controlling mechanism. As receivers there are high speed teleprinters, head-phones and loud speakers. Between the two there is the connecting link, just as real as the line wire, but because it is invisible generally ignored—the Aether of Space. All the signals pass from transmitter to receiver as Hertzian waves—aether waves; the air is not concerned in the transmission except as a hindrance at times, although it is often mistakenly supposed to do, probably owing to the popular expression "on the air." The difference

between ordinary and radio telegraphy may be very simply illustrated. Suppose a person A wished to send a sum of money to a person B in a distant town. A might enclose banknotes in a letter in which case B, on receiving it, would have the very notes that A had handled. On the other hand A might take his money to the post office and change it for a Money Order, a piece of paper of no value to anyone but the person named. He would send that to B who would change it at his post office into money. The first method corresponds to ordinary telegraphy, the second to radio. In radio telegraphy electric currents are changed into Hertzian waves, these travel through space with the velocity of light—300 million metres per second—and are changed again into electric currents at the receiving station. But there is no current passing between the two stations.

How are the necessary changes made? How are electric currents changed into Hertzian waves and these again converted into electric currents? Unfortunately the change is too easy; would that it were more difficult. Whenever an electric spark is produced as the result of a sudden disruptive discharge such as a flash of lightning, or the spark at the sparking plug of a motor car or even at the trembler of an electric bell, Hertzian waves are produced. In the early days of radio-transmission this type of transmitter was used. Whenever an electric charge accumulates on a conductor, striving to escape but held in check by the absence of a conducting path, the charge may become great enough to overcome the restraining influence, a sudden escape follows and an oscillating electric surge is set up. It is rather like a river breaking its banks as a result of an accumulation of flood water with the difference that in the electric case there is an immediate repair of the leak, whereas

in the river there is not. This picture must not be taken too literally for it is an imperfect one. What is wanted is to get a mental picture of something piling up and under restraint which goes on accumulating until the restraint breaks down and that which has been piling up escapes. But it does so very suddenly and in a sense overshoots, then a swing back follows, being repeated many times with gradually lessening swings like a heavy pendulum gradually coming to rest. The oscillations are very rapid indeed, occurring many thousands of times in a second. Anyone with a sensitive wireless set must have noticed that the switching on of a light, or the ringing of an electric bell affects the set. The minute spark discharge at the point of contact has set up Hertzian oscillations to which the set has responded. It is this ease with which Hertzian oscillations can be produced that makes interference so very troublesome. Thunderstorms in the tropics or in the upper atmosphere, electric trains and trams, workshop motors, vacuum cleaners, hair driers, violet-ray apparatus, are all likely to cause interference which is difficult to eliminate, chiefly because it cannot be "tuned out," for it is of many wave lengths mixed together.

Tuning, or "syntony" was first applied by Lodge; without it modern wireless would be impossible. Every system that is capable of free oscillation has a natural oscillation period and the oscillations occur in equal times. A simple example is a swinging pendulum. If the length is unaltered the swings occur at regular intervals, or are "synchronous." Shortening the pendulum increases the rate of swing, lengthening does the reverse. It is this principle that is made use of in the regulating of a clock. The vibration of a suspension bridge under traffic and of a factory

chimney in a strong wind are examples of the same thing. In radio-telegraphy the aerial serves the purpose of a regulating pendulum. At the place of transmission instead of the Hertzian waves being an unregulated jumble of waves of all lengths mixed together they are few only and simply related. It is rather like the difference between the jangle of noise produced by banging a lot of keys of a piano at random, and sounding a single note or a simple chord. The first stage therefore in syntony is the use at the transmitting point of an aerial to reduce Hertzian wave disorder to controlled order. Just as altering the length of a pendulum changes its rate of swing so does altering the length of an aerial change the wave-length of the Hertzian waves.

In our Money Order picture there was a change back again into money by the recipient. How are our Hertzian waves to be changed back again into electric currents? Here also the conversion is too easy. When a Hertzian wave meets an electric conductor, an electric oscillation is set up, that is, a single to and fro electric current and the Hertzian wave passes on, minus the small portion absorbed by the conductor, to do the same with other conductors. Think of the amount of such absorption going on! Trees, metal work of all kinds, houses especially in damp weather, people, are all conductors, Hertzian waves in abundance are speeding through space and consequently all these conductors have electric currents set up in them—feeble as a rule, it is true, but detectable and usable. What a blessing we have not an electric sense, if we had life would not be worth living!

Here again syntony plays a very important part

in modern wireless. If we have a pendulum at rest and we tap it gently at its own natural oscillation rate we can easily work up a swing in it. However feeble the taps a swing will probably "build up." If we tap it at some other rate there may be either no swing at all or a very imperfect one—there is no "building up." So with a receiving aerial, if the Hertzian wave "taps" arrive at exactly the same rate as the aerial can allow currents to oscillate—and this is largely dependent on its length—they will "build up" and in a very short time the oscillations will be sufficiently vigorous for reception. The aerial is then said to be "in tune," and the act of "tuning" is just bringing about this state of things. Since the waves follow one another at very short intervals—a 300 metre wave-length produces 1 million waves a second—the building-up time is only a small fraction of a second as a rule.

Mechanically, matter is inert, if at rest it wants to remain at rest, if moving to keep on moving. The circuits in which rapidly alternating currents occur also possess a sort of inertia, a disinclination to change. This is known as "inductance." They also behave as though the electricity required a time to sink into them, a property known as "capacity." Both these effects depend on the relative positions of the conductors concerned and can be controlled with exactitude. Tuning is effected by varying the inductance and the capacity of the circuits. In some sets tuning coils are inserted to alter the length and inductance of the aerial. In others merely turning a knob effects the same purpose. Capacity is almost always changed by

the turning of a knob attached to a variable condenser so that the tuning of a receiver is now made a very simple matter.

The next thing to consider is how the currents oscillating in the aerial can be made to reproduce the sounds from the transmitting station. For radio-telegraphy the matter is fairly simple. All that is required is the production of signals of some sort of long and short duration—the Morse Code—and it doesn't much matter what they are. Of course in actual working the signals most suitable for each requirement are employed. But radio-telephony is a different matter altogether. The pitch of the sound, the tones and overtones, all those peculiarities that distinguish a voice, the particular quality of sound that differentiates between a violin, a cornet, or a flute, must be faithfully reproduced. Whatever changes may take place, however many conversions and reconversions there may be the tonal qualities must be preserved. And how many changes there are! An orchestra is playing in a broadcasting studio, stringed instruments, wind instruments, drums, and perhaps voices are producing air waves of all sorts, shapes and sizes, and one poor microphone has to deal with the lot. But there is only one thing it can do with them. There is a small steady electric current flowing in the microphone. The air waves falling on its sensitive diaphragm cause minute variations in the current which *must possess all the qualities which characterize the sounds.* But they are now no longer sounds, only electric currents. These are now intensified or "amplified" several times until they are capable of producing Hertzian waves of sufficient vigour for the purpose required. This

change into Hertzian waves can be effected in various ways, the most usual being by means of specially designed oscillation valves. And so they are launched into Space, but *here again they have to* possess all the characteristics of the currents. Up to this point there have been at least four conversions and now there follow at least four more to get the sounds reproduced. When we consider the number of changes made and realize that in each case all the peculiar characteristics have to be maintained the faithfulness of modern wireless reproduction is little short of marvellous. Let us follow this second series of changes. The aerial if it is in tune absorbs a small bit of the energy of the incoming waves, converting it into oscillating electric currents. These pass through various circuits which must be in tune with each other, being amplified if necessary, and then to a very important part of the receiver called a "detector," which cuts off half the oscillation making the currents uni-directional. After this they are still further amplified if necessary and now pass to the loud speaker or other reproducing apparatus. In the case of telephony the currents act magnetically on a vibrating disc producing the waves of air which the ear translates as sounds. These air waves have the pitch and quality of the original sound waves at the place of transmission. A truly remarkable and I fear often unappreciated achievement!

There are two main sets of Hertzian waves emitted from the transmitter. There is first the "carrier wave," which is peculiar to each station constituting its transmission wave-length. A 300-metre station sends 1 million waves a second, a 100-metre station sends 3 million a second, the frequency being always

$\frac{300{,}000{,}000}{\text{wave-length}}$. The number of electrical oscillations in the receiving circuits will of course be the same. Even supposing the vibrating part of the receiver could vibrate at such a rate, which it cannot, the human ear could not perceive anything. Very few people can hear air vibrations of more than about 20,000 a second. The middle C of a piano has a frequency of 256 a second and for each octave higher the number is doubled. There thus emanates from each transmitting station a series of supersonic waves which because of their high frequency produce no audible result. We can easily imagine them stretching in all directions like invisible telegraph wires. And they serve the same purpose. Superimposed on them is a second set of waves, the sonic ones, produced by sounds at the transmitting microphones, to these the recording apparatus and the ear can respond. Two carrier waves of different frequency can interfere with each other and produce a wave whose frequency is their difference. This is called "Heterodyning" and is the cause of whistles, shrieks and howls that are often so objectionable. When properly regulated it can be advantageous as in "Continuous wave" telegraphy, and in the "Supersonic Heterodyne" type of receiver, popularly known as the "Superhet."

Let us now consider the Receiver. We are not dealing with all the details and technicalities of reception, for those the reader must be referred to the many books on the subject. We are concerned here with principles only. There are three main sections of a receiver—the high frequency section, the detector, the low frequency section. The first

named deals with the carrier wave current, amplifying it when necessary, giving it more energy. The last named similarly amplifies the sound-frequency current —acts as a "note magnifier." The detector "rectifies" the current, that is, changes it from an oscillating to a uni-directional one.

In the early days of wireless much interest was centred in the detector, improvements in which played an important part in wireless development. One of the earliest was the "filings coherer," which even now has its uses. Others were the "Lodge-Muirhead," the "Magnetic," the "Electrolytic," the "Crystal." Judged by modern-day standards they were most inefficient and unstable. Moreover signals from distant stations were very faint because there was no means of amplifying them. Just as a ripple on a pond dies down with ever increasing distance from its centre so does a system of Hertzian waves become attenuated at a long distance from the place of origin. Nowadays such a feeble wave can be amplified to almost any required degree in a succession of stages. It is something like changing the tired horses in the old stage-coaching days, replacing them with fresh ones to be replaced in their turn at the next stage. This has become possible by the invention of the "Oscillation Valve." Certain peculiarities in the behaviour of ordinary electric lamps led to its invention by Prof. Fleming. An improvement in it by Dr. de Forest increased its efficiency until to-day it stands pre-eminent for a great variety of purposes. Without it broadcasting would not have been possible. It has been improved to such a degree that now one valve can do efficiently what a few years ago several could only do poorly.

It varies in size from the small glass bulb of the ordinary receiving set to a huge all metal one about 10 feet high and weighing over a ton.

An ordinary oscillation valve has three essential parts, a FILAMENT, a GRID and a PLATE or ANODE. In modern special purpose valves there are several grids and plates enabling one valve to serve the purpose of many. We propose to describe simply the ordinary three part valve or "triode." Fleming's original invention had filament and plate only, it was a "diode," the grid was afterwards added by de Forest, an improvement that added considerably to its utility.

The filament is heated by an ordinary small current like an electric lamp, or it may be heated indirectly, at any rate it must be raised to the required temperature in some way. When heated it emits a host of "electrons," in fact we may look on it as merely an "electron factory." We must remember that these are almost inconceivably small and negatively electrified. They swarm all over the inside of the valve like a swarm of bees. But we don't want this, so they are constrained to travel in a definite direction—in a very simple way. The "plate," a strip of metal which may have many shapes, is positively electrified either by a "high tension battery" or in some other way. Since oppositely electrified bodies attract one another the positively electrified plate attracts the negatively electrified electrons and thus an "electron stream" travels through the valve from filament to plate like a steady breeze. This constitutes an electric current, feeble it is true, but definite in amount. An electric circuit is completed between the plate and filament consisting of the electron stream within the valve

and an external wire to complete it. Somewhere in this circuit the recording apparatus, loud-speaker for instance, is connected. There is therefore a steady uniform current flowing in the circuit filament—plate—loud-speaker—filament. But a uniform current flowing through the coils of a telephone or loud-speaker produces no sound beyond a click at start and finish, current variation is necessary. This is the function of the grid which is a network of wire in the valve between the filament and the plate and which is connected to the aerial. The electrons on their way from filament to plate must pass through the mesh of the grid. Since we conventionally regard an electric current as flowing from positive to negative all the parts of an oscillatory circuit are alternately positive and negative. The grid therefore is sometimes one, sometimes the other. When it is positive like the plate it helps the plate increasing the electron stream, when it is negative it hinders the plate, decreasing the electron stream. It thus *controls the electron traffic* in the valve, and the varying currents which result from this control passing through the loud-speaker produce the sounds. There are valves of many forms for many purposes and of many degrees of complexity, details of these must be sought in more technical works, we are here concerned only with the principle underlying valve action. Valves are variously designed according to the purpose they are to serve, detector valves, high-frequency amplifying (H.F.) valves, low-frequency note magnifying (L.F.) valves and many others. The detector valve is the "key" valve, the oscillating currents are to be rectified by it, that is rendered non-oscillating and it can only deal with them if they are sufficiently vigorous. Weak signals therefore must be given more

energy and it is the function of the H.F. amplifying valves to do this before passing them on to the detector. After rectification they probably require still further amplification before they are energetic enough to produce loud signals. The L.F. amplifying valves do this. It is the ability of the oscillation valve to amplify weak signals that has made it pre-eminent as a vital part of modern wireless apparatus.

Owing to the very rapid increase in the number of transmitting stations sharpness of tuning has become of vital importance both for transmitters and receivers. To avoid interference the waves emitted must not be too broad and must be accurately measured. If two stations are sending out waves too near each other in length both will be picked up by a receiver with resulting confusion. There is a minimum wave length separation which should be observed. The more sensitive the receiver the more difficult it is to eliminate this trouble. It has become a matter of the highest importance that transmitters should maintain unvarying wave-lengths and that receivers should be highly selective. A high state of perfection has been reached in both directions, but a good deal of station interference still exists. Several International Conferences have been held in order to secure freedom from overlapping but strict adherence to arrangements has not always followed. It is a very difficult matter to reconcile the conflicting claims of the nations of the world respecting the number and the output power of their transmitters. Much ingenuity has been shewn in controlling the sensitivity and selectivity of receivers so as to cut out unwanted signals. It is for this purpose that valves of intricate

design and many tuned circuits mutually reacting have been evolved.

Of the many benefits that wireless has conferred on mankind there are a few of which mention should be made. First we may mention the time services. In addition to the well known signals such as Big Ben and the six "pips" from Greenwich Observatory, there are scientific ones sent by special code from many different parts of the world which are accurate to about $\frac{1}{100}$ second. These are picked up at sea and serve to correct ship's chronometers and thus assist navigation. They are also used in large scale geodetic survey work and in exploration. The Eiffel Tower time signals for these purposes were well known to wireless workers in pre-War days.

Another valuable wireless service has to do with Meteorology. Full particulars of pressure, temperature, barometric tendency, humidity, wind and cloud movements at various elevations, are sent out at frequent intervals throughout the day, mainly for the benefit of aviation.

Direction finding stations for shipping and for aircraft are distributed round the coasts of many countries. In bad weather conditions ships at sea and aircraft aloft unable to take their bearings send out a call for position. This call is picked up by two or more direction-finding stations which by means of specially designed aerials can detect the direction from which the call is coming. Station A finds the signal is coming in a certain direction, station B finds a different direction. By combining the two results the position of the ship or aircraft is ascertained with fair accuracy and a signal giving the position is sent out.

Only bare mention need be made of calls for assistance by ships in distress. When the rather awe-inspiring S.O.S. is received all other wireless working immediately ceases, the distress call being repeated to ships within reach.

Another help to shipping is the wireless "beacon" or "lighthouse." At certain danger points special signals are sent out sometimes in ever changing directions which can be picked up by the receiver in much the same way as a light signal is perceived visually. But whereas lights are impaired by fog and snow squalls the wireless signals are practically unaffected.

Another step in wireless progress is the wireless "Beam." A light shining in the open is dissipated in all directions and diminishes rapidly in intensity with increasing distance. The same light concentrated in a beam by a lens or a concave mirror can penetrate very much further. Similarly Hertzian waves can be concentrated in a beam in a definite direction by reflection. For this purpose the wave-length must be short and the reflector is a screen of vertical wires placed at a carefully calculated distance behind the aerial. By this means "Beam Stations" using wave-lengths from a few metres up to about 80 metres can send out signals that encircle the earth and require only moderate power. The wireless service linking up all the principal parts of the Empire is of this kind. Of course a narrow beam can only be picked up by stations in its direct line, but it cannot be broadened too much, so as to serve more places, without diminishing its effectiveness. As a rule the transmitting and receiving stations are separated by some distance, for instance, the beam service communicating

with Canada and South Africa has its transmitter at Bodmin, Cornwall and its receiver at Bridgwater, Somerset. The signals from wireless "lighthouses" are sent by the beam system.

A pertinent question that might be asked is "How does the wireless signal manage to overcome the curvature of the earth?" Wireless waves and light waves are similar in kind, differing only in degree. Light rays are proverbially straight and if wireless waves are the same they would pass well above aerials a few hundred miles away and be lost. The answer appears to be this:—Part of the wave remains "anchored" to the earth, stepping along it as it were, following its contour wherever it leads. This is known as the "ground wave." The remainder travels out into space and would be lost but for the various atmospheric "layers." At a height of about 70 miles but varying with time, season and weather is a region of the atmosphere that can reflect or refract the waves. This encircles the earth like a ceiling and is known as the "Kenelly-Heaviside" layer. Beyond this at about twice the height is another layer or ceiling known as the "Appleton" layer, and there are believed to be others at still greater elevations. The waves are therefore confined within these corridors much as air in a speaking tube is confined. Just as light is reflected from a polished surface or refracted on passing through a certain transparent media, so the wireless waves are reflected or refracted by these layers and brought back again to earth. Some waves are kept to the lower "storey" by the first layer or ceiling, others pass through but are caught in the next storey, and so on. Were some such action as this not operating the long distance

signalling with absurdly small power that has been accomplished would be impossible.

Wireless broadcasting has grown from very small beginnings. Very soon after the Great War broadcasts of music were sent out from Holland. An English newspaper did much encourage it, an early broadcast being given by Madame Melba from Chelmsford. Following this were bi-weekly broadcasts of about two hours each from Writtle in Essex in 1921, until to-day it is world-wide and has become of national importance.

CHAPTER IV

X-RAYS

The discovery of X-rays, an outstanding event of 1895, was an outcome of a long series of investigations into the mode of conduction of electricity in non-solid conductors. In any list of names of those contributing to the result a prominent place must be given to Faraday, Crookes, Thomson, Röntgen and Lenard.

Not only was the knowledge of electric conduction advanced but light was thrown on the nature of matter. It must be remembered that a good deal of the 19th Century—the first two-thirds of it at any rate—was concerned with the nature and mutual relationship of atoms and molecules. During this period the atom was regarded as an indestructible, indivisible entity, exceedingly minute and rather like an ultra-microscopic pea or pellet. It was not only the smallest particle that could take part in chemical action, it was the smallest particle that could exist.

Faraday and his successors had shewn that in the conduction of electricity through liquids there was an actual movement of particles sometimes of atomic dimensions, sometimes of larger groups, carrying the electric charges along like porters carrying luggage and these carriers were called *ions*. Heat was known to be transmitted in three ways—conduction, convection and radiation—electricity was thus transmitted in the first two ways, the third way—radiation—was to be discovered later. Ions may be of many dimensions and degrees of complexity from very

simple ones like atoms to groups of atoms and molecules, but whatever their sizes they were called "ions" because they "travel" carrying the electricity along with them. Their speed and the sizes of their electrical "bundles" were determined and accurately measured. Considerably more energy was required to transmit electricity in this way than through a good solid conductor, that is to say many more volts were needed.

Bad as liquids are for conduction gases are much worse; when dry and at normal pressure they are almost perfect insulators. To drive an electric current across a 1 inch gap requires an electromotive force of about 50,000 volts, yet there are conducting ions present at all times. They can be removed from air by bubbling it through water or by filtering it through cotton wool. Their number can be increased in many ways by X-rays, by ultra-violet light or by the presence of radioactive substances, nevertheless they are not sufficiently numerous to make air or gases generally good conductors.

Investigations on the conduction of electricity through gases were carried on during many years following 1870, work in which Sir William Crookes was closely connected. We will follow this in some detail as far as the main line of research is concerned so as to shew how step by step a discovery of an epoch-making character was made. During a thunderstorm tremendous electric charges accumulate which tend to discharge between cloud and cloud or between clouds and earth. The discharge takes the form of a vivid flash of light accompanied by the familiar peal of thunder. The flash is irregular, rather like a river on a map with many tributaries. When air

is enclosed in a bulb and a discharge passed between two metal rods within the bulb a lightning flash in miniature is produced of similar form to natural lightning accompanied by a sharp snap which is a miniature thunderclap.

The main observations with which we are concerned were to discover how the discharge would change with changes in the pressure of the gas. Imagine therefore a glass bulb with a connexion to an air-pump so that the pressure could be steadily reduced. Within the bulb and several inches apart were two metal rods ending in round knobs, the one where the current entered termed the "anode" and the other the "cathode." An induction coil capable of giving a current of many thousands of volts was also required. Starting with the air in the bulb at normal pressure, i.e., 30 inches or 760 millimetres, the discharge was a sharply defined river-like line of light accompanied by a sharp snap. The air pump was now set going and any changes noted. As pressure was reduced the sharp outline of the spark gradually disappeared and a much broader luminous column stretched from anode to cathode; meanwhile the sharp snap gradually changed to a gentle hiss. Still further reduction of pressure produced striking changes in the appearance of the luminous column. With pressure at about 50 millimetres (c.p. 760 m.m. at commencement) the luminosity filled the bulb. After this it appeared to break up into bright and dark bands rapidly flickering. At 3 m.m. the cathode was covered with a bright luminous shell bounded by a pronounced dark space—which is generally known as the "Crookes dark space." As exhaustion proceeded further the "Crookes space" gradually

became broader until eventually it completely filled the bulb and there was no luminous column left. By this time the pressure was very low indeed—approaching a complete vacuum. At this stage something new appeared, at a point opposite the cathode the glass glowed brightly. Further experiments showed that the colour of the glow—called the "fluorescence"—depended on the composition of the glass, and was always opposite to the cathode. There thus seemed to be something passing across from the cathode which was later found to be capable of being focussed by making the cathode concave. It therefore appeared to be probable that the "cathode stream," as it was called, consisted of something travelling from the cathode in straight lines. It was found that when it was focussed on a small target of platinum, the target became red-hot. The explanation suggested was that the stream was one of tiny bullets travelling at high speed and producing heat by bombardment, just as a stream of bullets from a machine gun would heat up a target at the point of impact.

Many experiments were carried out to test the suggestion of bullets in straight line flight. One was the well-known Maltese Cross experiment where an obstacle shaped like a Maltese Cross was placed in the line of fire causing a dark clearly defined shadow on the brightly fluorescing glass of the bulb. Another bulb contained a tiny railway on which a paddlewheel rested which could be driven to and fro by cathode streams from cathodes in various positions. There appeared to be no doubt therefore that in a highly exhausted bulb the cathode emitted a stream of rapidly moving particles. Further research led to the very surprising conclusion that *they were of much less*

than atomic dimensions. This conclusion gave rise to considerable discussion but was definitely settled by J. J. Thomson in 1897. It was shewn also that the stream could be deflected by a magnet, that it seemed to be composed of particles negatively electrified.

Thus as the result of work spread over many years the definite conclusion was reached that gases in a highly attenuated condition exposed to electric discharge could yield a stream of negatively electrified particles of sub-atomic size, now known as "electrons." This stream could produce very beautiful fluorescent effects when directed on to many different substances, one substance which fluoresces very readily being barium platino-cyanide. Further attempts to get into close contact with the particles failed because they were locked up in a glass tube and the key was missing. Eventually Lenard found that by making a hole in a glass tube and filling it in with a sheet of aluminium, that is by putting an aluminium window in a glass tube, and directing the cathode stream on to it some particles passed through. Less was learnt about them than was hoped because they were so easily stopped by the relatively more massive atoms and molecules of the air.

We now come to a discovery of far-reaching importance by Röntgen in 1895 at Würzburg. Working with cathode rays after the manner of Lenard, in a darkened room and with the tubes wrapped in an opaque covering, he noticed some fluorescent material a little distance away glowing quite distinctly. It was much too far away for any Lenard rays to have reached it. Another curious thing was that some photographic plates in a box in the room became fogged and an impression of the lock of the box appeared on them.

Investigation convinced him that the effect was not due to the cathode rays but must be due to some other ray whose nature he could not determine. To this ray he gave the name of the mathematical unknown quantity "X." The announcement in 1895 of the existence of this new X-ray which could penetrate substances opaque to light and could disclose coins in boxes or leather purses, or bones in the living body not only excited scientific interest but very quickly struck a popular note.

X-rays are produced whenever rapidly moving cathode rays are suddenly stopped. They differ from the cathode rays in not being material particles. Their precise nature was for some time a matter of uncertainty. It was realized that they were somewhat akin to light, it was thought that perhaps they might prove to be longitudinal pulses in the aether but it is now definitely shewn that they are of exactly the same nature as light but of much shorter wave-length. Their power of penetration of matter is related to its "density" and not its "kind." The less dense it is the more easily it is penetrated, wood therefore is more easily penetrated than glass, and flesh than bone.

In principle an X-ray tube is simple, the only requirements being a stream of rapidly moving electrons and a plate of some resistive material—the "anti-cathode"—which they bombard and which checks their flight. At present the only means of obtaining a suitable electron stream is a highly exhausted bulb or tube and a high electrical voltage. The latter is however only a means to an end. If the stream could be obtained in any other way it would serve the purpose equally well. A modern

X-ray tube is much more complicated. The electron stream is under control both as regards amount and velocity; the anti-cathode target is made of various metals and kept at a uniform low temperature so that the degree of suddenness of the electron stoppage can be regulated. The result is that the amount and the penetrating power of the rays can be regulated to a nicety. That wood should be transparent to the rays and glass opaque is not so odd as may seem at first sight for glass is also opaque to heat rays—we use glass fire-screens—whereas certain solutions of iodine are transparent to heat and opaque to light. None-the-less the power of penetrating bodies usually regarded as opaque and disclosing their hidden interiors made the discovery one of outstanding interest. Popular demonstrations became the fashion and people became aware of some of the details of their bony structure. To some this disclosure was rather disturbing. The writer can recall an incident when a very "proper" lady approached a demonstrator remarking that she understood the rays could not penetrate black velvet. She was wearing a black velvet coat and was horrified to find that her skeleton was perfectly visible on a fluorescent screen.

Many are the uses to which the rays are put. Their application to the detection of foreign bodies, fractures, dislocations and malformations must be obvious, opening a new chapter in surgical practice. There is one important difficulty however. Whether a photograph is taken to get a permanent record or a fluorescent screen is used—generally barium platino-cyanide on cardboard—the image shews no perspective, it is merely a shadow and the precise position of an object requires several views in different planes. The

image is thus a "shadowgraph" or "skiagraph."

Owing to the increase in penetrating power in modern X-ray appliances their use has become much extended. The internal parts of steel castings can be examined for defects such as blow-holes, hair cracks and blisters, the uneven distribution of the components of alloys can be detected and defects in welding, soldering and brazing. Hidden corrosion in steel gas cylinders might cause serious accident which is avoidable by X-ray examination; the armouring of submarine telegraph cable can be examined and cable interruption prevented. Among a host of useful applications one may mention the examination of timber for heartwood or sapwood, knots and grub holes in timber, motor tyres for the union between rubber and fabric, concealed wiring in houses and aviator's clothing, oysters for pearls, artificial jewels, contraband, foods for adulteration, shoe fitting. A bad golfer may blame the ball for a faulty flight, but many best quality balls are examined to see if the inner core is free from distortion, thus many a poor golfer has lost a plausible excuse. Art too has called the rays to its aid. Differences in pigments used by some of the Old Masters have led to the detection of alterations in some of their pictures, the original impression being recognisable.

Unfortunately the rays have an injurious effect on those who are exposed to them for long periods unless precautions are taken. The early pioneers not realizing the danger paid the penalty, some with their lives, others with the loss of limbs and other permanent injury. Now that the dangers are known proper safeguards are adopted, protective dress is worn and in up-to-date apparatus the rays are

prevented from scattering. This action on living tissues has been turned to good purpose in the treatment of many ailments and X-ray "treatment" is now part of regular medical practice.

To turn again to the purely scientific aspect of the rays, it will be remembered that gases are very poor conductors of electricity, almost insulators in fact. The air is slightly conductive owing to the presence of certain numbers of wandering ions. These can be removed in various ways such as filtration or washing and the air rendered non-conductive. A stream of X-rays makes it conductive again, that is, causes "ionisation" by detaching a small portion of an atom, both the fragment removed and the remaining portion becoming ions and acting as conductors.

To sum up: X-rays are not material things, they are of the same nature as light and Hertzian waves but of very much shorter wave-length. They are produced when cathode rays, which are material things, travelling at high speed, are suddenly stopped. They penetrate matter with a readiness depending on density and not on its nature; they are invisible but cause many substances to emit light; they act on photographic plates like light; they induce important changes in living tissues; they cause ionisation in gases through which they pass and as will be seen later they help to throw a light on the structures of molecules and the constitution of matter generally.

CHAPTER V

LIGHT AND THE SPECTROSCOPE

An instrument of great simplicity yet of outstanding benefit to the chemist, the physicist and the astronomer especially is the Spectroscope. It has been the chief means of discovery of many new elements and their definite identification. It has pushed back the boundaries of the visible Universe to a distance previously undreamt of, has given us valuable information of the present constitution of heavenly bodies, something of their past history and future destiny, yet the instrument itself owes its existence to the observation—by a genius—of a beam of light passing through a hole in a shutter. The purpose of this chapter is to describe the instrument and some of the results achieved by means of it.

First we must say something about light. The first thing we shall say may seem rather odd. It is that light is invisible, that is to say it cannot be seen as it passes from one point to another except in the line of flight. It is as if one were unaware of a motor car until it knocked one down. But an objector might say: "Surely there is something wrong about such a statement; we have seen beams of light from a lantern or a lighthouse without standing directly in their track." A simple experiment would however confirm the statement. If the beam of light is allowed to pass through a glass box either devoid of air or with the air rendered free from dust, no visible track will be seen. A similar experiment is performed for us on any clear night

when a planet such as Venus or Jupiter is visible. Such a planet has no light of its own, it merely reflects sunlight that falls upon it, yet we look in vain for the light passing from the sun to it. Why? Because there is neither air nor dust between the two. A lighthouse or lantern beam is visible because particles of dust in the beam-track, by reflecting the light and scattering it, become visible themselves and mark out the track of the light.

The question might now be asked: "Then what is light?" At one time it was thought that it was instantaneous, that if a distant light is switched on there is no time interval between its occurrence and our perception of it. Galileo had thought differently and had tried to measure the time interval, but the experiment was too delicate for him, so he failed. It was left to the Danish astronomer Roemer to supply the proof in 1676. He noticed a delay in the eclipse times of Jupiter's satellites when the planet was most distant from the Earth as compared with those when he was nearest and concluded the reason to be the time required for light to pass across the Earth's orbit, a distance of about 186 million miles. This gave a value for the velocity of light so great that for a time doubt was expressed about the value of the deduction. Subsequent experiments however swept away all doubt. A homely illustration in connexion with sound may help in the understanding of Roemer's observation. Imagine a business man with an office in a town near a public clock but living two miles away. Setting his watch by the clock he goes home and a little later hearing the clock strike consults his watch and finds it is ten seconds fast. He alters it and going to his office

next day and comparing it with the clock finds it ten seconds slow. Putting it right again he finds it again ten seconds fast when he gets home. Thinking over this erratic behaviour of a previously well behaved watch he realizes that it is still really faultless and the true reason is that the sound of the striking clock takes ten seconds to travel the two miles. Substitute the satellite eclipse for the clock and the observer on the Earth for the business man and the reason for the variation in eclipse observation times will be obvious. At the same time it is still difficult for many people to realize that when looking at a star they may be seeing it not as it is now but as it was in the far distant past before recorded history.

As regards the nature of light the first theory was a corpuscular one, that it was the result of a flight of light—corpuscles of very minute size travelling in straight lines from the luminous object to the observer. This was the "Emission Theory." This satisfactorily explained many of its properties but failed to explain polarisation and diffraction. It could not shew how the addition of two lights could produce darkness. In spite of the strong support of Sir Isaac Newton for the theory it had to be abandoned.

A few words about Theories may not be out of place here. It is often thought that when a scientific theory is discarded science has suffered a set-back. This is not the case, rather the reverse. It is more correct to regard a theory as a convenient working tool. When it fails to serve its purpose it must be put aside and a better one employed. The relation between theory and experiment is briefly this: In physical science certain experimental facts are observed; after a while a theory is built up explaining these

facts and forecasting further results of experiment. For some time, it may be, the forecasts are confirmed and the Theory becomes established. Then as the result of some new piece of apparatus or a new line of attack a forecast is refuted. The theory then is either corrected or amplified or perhaps abandoned altogether and a new one in accordance with the more recent facts supplants it. *But the final court of appeal is experiment.*

Now to return to the Emission Theory of light. It was found inadequate to explain diffraction, but perfectly satisfactory in other ways and was abandoned with reluctance. In the early years of the 19th century the newer "Wave Theory" took its place. According to this light is the result of waves emanating from the luminous body and spreading out in all directions. During the greater part of the century it reigned supreme and there seemed no reason for disquietude about it. But, meantime, methods of experiment were improving and a large body of research workers was hard at work discovering new facts. We have seen that first Matter was found to be discontinuous, atomic in character; then much later electricity proved to be also atomic. Towards the end of the century it became suspected that light in one of its aspects was also atomic. In addition to rendering objects visible light can cause chemical change, can exert pressure, can set electrons free from their atoms, and in this connexion it seems to be atomic. In other words in the radiation of light *energy* any changes that occur do so, not continuously like the passage of waves, but by "jumps" as though it consisted of a stream of bullets. We are thus back again to the corpuscular theory. But we cannot

abandon the wave theory because without it diffraction cannot be explained. We are therefore in the unsatisfactory position of having to accept both. In its luminous effects it behaves as a wave, in its energy effects it is more like a stream of separate particles. Max Planck in the early years of this century was responsible for the "Quantum Theory" which deals with this.

As we are concerned in this chapter with the optical properties of light we can ignore this dualism and consider it to be a wave. Since we probably do not know much about anything as regards its true nature we have to deal with things as they appear and a century hence with the acquisition of further facts our outlook might be very different. Since gravitation behaves like a "force" it *is* a force until time and further knowledge shew it to be something else, so too in its optical aspect light appears to be a wave, therefore it *is* a wave until it can be shewn to be something else.

A wave demands a medium in which vibrations can take place and as in the case of wireless it is the "aether." It is difficult for the plain man to picture a medium that pervades everything, to which nothing is "solid," which is invisible and intangible, in which waves can be produced and can travel at the rate of 300 million metres (186,000 miles) a second. But because it is difficult or unthinkable is no reason why we should reject it. The natural world is full of marvels, teeming with them. We only need to look through a microscope or a telescope to realize this. Let us not therefore look upon the aether as an imaginary thing, a something that scientists have invented to get themselves out of a fix. Let us accept it and make use of it until some-

thing better can be found. If anybody had said 50 years ago that we could sit in our room and listen to somebody speaking at the other side of the earth we should have regarded him as a fit candidate for an institution for the mentally-afflicted. What would our forefathers of a few generations ago have thought of the modern routine of the X-ray examination? (From this point of view the aether is a medium filling visible Space and pervading all Matter, capable of vibration whose waves may have lengths—wave-intervals would be better—ranging from miles to ultra-microscopic dimensions, but all travelling in free space at the same speed of about 186,000 miles (300 million metres) a second. There are several marked differences in the effects of the various wave-lengths. The very long ones from several miles long to an inch or two produce mainly electrical effects. Much shorter ones are thermal and can be detected and measured by heat-measuring instruments or nerves of sensation. Shorter again are optical, seen by the eye as light. Still continuing the ever-shortening wave-lengths we find "actinic" waves or ultra-violet waves, then X-rays followed by "Gamma" rays of radioactivity, and finally the "Cosmic" rays. Taking sound as an analogy and remembering that each higher sound octave halves the wave-length, there are over 40 octaves of the aether waves with the long Hertzian waves representing the deep bass and the Cosmic and Gamma rays the high treble. Of this long series the visual waves occupy *only one octave.* The longest ones are those of red light, $\frac{1}{30,000}$th of an inch long, the number of waves per second—the frequency—being about 350 billion (million-million)! The shortest visual ones are half this length,

therefore there are about 700 billion a second!) Numbers like these are rather startling, but we have to try to picture them especially as there are much shorter wave-lengths and therefore greater frequencies in the actinic rays, X-rays and the rest reaching frequencies of over a million times those of light. We are here attempting to impress on the reader that there is a long series of aether-wave frequencies forming a continuous band with no breaks in the continuity, the only breaks being in our means of detection; some we detect by electrical instruments, others by heat-measuring apparatus, others by the eye, others again by photography and so on, the waves themselves are continuous and the long ones differ from the short ones much as big Atlantic rollers do from tiny ripples on a pool.

Within the single octave limit of the visual frequencies each wave length corresponds to a definite colour. Thus starting with the longest visual waves there is a group of frequencies whose effect on the eye is expressed as "redness," ranging from the deepest red that is visible to a pale orange-red. Another group gives the general idea of "yellowness," another gives "greenness" or "blueness," passing eventually to deep violet, which marks the upper limit of visibility. But within each group there is almost an infinity of "shades" or "tones" corresponding to either individual wave-lengths or smaller groups of them. We can therefore describe a wave-length by its colour—if we have a sufficiently accurate standard and means of measurement—or by its actual wave-length in some suitable unit. The latter is the plan adopted for accurate scientific purposes, the unit being the "Ångström" or "A," and is equal

to one ten-thousand millionth of a metre. In terms of this unit visible wave-lengths range from about 7,600 A in the red to 3,900 A in the violet. We can label a house as No. 42, High Street, or as "The Laurels." The former is the better plan, because it describes the position more definitely. Similarly, we can label a wave-length as "green" or as "5,000 A" and the latter is by far the more accurate.

Ordinary white light cannot thus be labelled because it is not one thing alone, it is a mixture of every colour. The mixing is done by ourselves, we perceive the colours—or certain colour groups—separately, mix them up and the result passed on to the brain is what we call "white." When we admire the whiteness of fresh snow what we really "see" is red, green and blue, the whiteness is our subsequent interpretation of the combination.

We see a thing for one of two reasons; either because it emits light or it reflects light. We see the sun or a star or a lighted candle because they all emit light of their own on account of something that is going on within themselves. We see the moon or a picture or a landscape, because they reflect light. Different parts of them reflect differently, none reflect all the light they receive, some is absorbed or retained and the remainder reflected. This gives the various degrees of light and shade, enabling us to distinguish objects. If white light falls on an object and it reflects in the same proportion as it receives it appears white, otherwise it will appear of some other colour. A red ribbon is red because it absorbs the other colours and reflects the red; grass is green because it absorbs, bottles up, keeps back, the red, the yellow and the rest, reflecting only the

green. They are red or green, not because red or green has been *added* to white, but because the other colours have been *abstracted.* Their colour, therefore, is not due to addition but to subtraction. Similarly, a red signal light is red because the glass blocks the passage of all the colours except red.

The expression "Seeing is believing" is to many people almost a truism. As a matter of fact light plays many pranks with our eyes. We see an object in a certain place and we are apt to believe that it really is there. At sunset on the coast we see the sun dipping below the horizon, whereas it is really some distance below it; we see the water in a swimming bath apparently 3 feet deep when it is in reality 4 feet deep; a desert traveller sees trees and vegetation and all the signs of the presence of water at a point where there is nothing of the kind. All this happens because rays of light do not always travel in straight lines. If a ray passing from a medium of one density into that of another density meets the boundary of the two obliquely it becomes bent. Such a ray passing through a triangular prism of glass after meeting the prism-face obliquely is bent towards the base, on emerging at the other side into the air again it is again bent. This is known as "Refraction." Light rays from the setting sun passing through layers of air of various densities are bent round towards us and so the sun appears lifted up above his actual position, since we see an object in the direction in which light from it enters the eye. The heated air above desert sands similarly refracts the light rays from an oasis below the horizon, bringing it into view and making it appear much nearer than it actually is. In determining the position of a star a correction has to be made

depending on its height above the horizon where refraction is greatest.

When a beam of light consisting of rays of various wave-lengths is refracted, the longer wave-lengths are refracted less than the shorter ones. Thus a beam of white light passing through a triangular glass prism is spread out into a rainbow-coloured band with red at one end and violet at the other and the other colours in between. This coloured band is called a SPECTRUM. It was in 1675 that Sir Isaac Newton shewed that white light consists of coloured lights of different refrangibilities mixed together. His experiment is historic. He allowed a beam of sunlight to pass through a hole in the shutter of a darkened room. The refracted beam was received on a sheet of white paper on the opposite wall. Instead of getting a round image of the sun he obtained an elongated rainbow-coloured band in which he noted the colours red, orange, yellow, green, blue, indigo and violet; the red being refracted least and the violet most; this was the spectrum of sunlight.

In 1814, a Bohemian optician named Frauenhofer, using a particularly fine prism, noticed that the spectrum was crossed by a number of dark lines of varying degrees of blackness and irregularly distributed. He was able to count nearly 600 of them and indicated the more prominent of them by the letters of the alphabet—D-line, F-line, &c. Although he was not the first to notice them, for they had been seen by Wollaston many years before, they have been called "Frauenhofer's lines."

An instrument designed to produce and shew a spectrum is called a SPECTROSCOPE. It consists essentially of a tube, at one end of which is an adjustable slit, through which the light to be examined is

allowed to pass. At the other end is a lens to suitably dispose the light rays on to the face of a triangular prism. Refraction takes place on its passage through the prism and a spectrum is produced which is observed by a small magnifying telescope pivoted on the stand. A typical spectroscope would have the tube through which the light is directed—the "collimator" tube and the viewing telescope tube about 10 inches long and 1 inch diameter. Much larger ones are used for special purposes, whilst small direct-viewing ones could be carried in a waistcoat pocket. Mention must be made of another kind, the "grating" spectroscope, in which the prism is replaced by a "grating," either a piece of glass on which very fine parallel lines have been ruled with a diamond point or a reflecting metal surface similarly ruled.

For many years after the detection of the Frauenhofer lines lights of all kinds were examined, amongst those engaged in the work being Herschel, Talbot, Brewster, Bunsen and Kirchhof. By 1860, the spectroscope had become an instrument of precision by the discovery, in that year, of two new elements, Caesium and Rubidium. After this a new branch of investigation, "spectrum analysis," became of immense service to chemical research. Its sensitiveness is such that substances in amount far too small to be detected by the balance can be detected with comparative ease. Many new elements were discovered by means of it as well as impurities in existing ones.

There are three main kinds of spectra—the "continuous," the "bright line" and the "absorption." When light from an incandescent solid or liquid body is examined the spectrum is a continuous rainbow-like band without any marks or breaks in it. It may extend

from red to violet through the intermediate colours or it may be curtailed, but where it exists it is unbroken. Gases under certain conditions give a similar spectrum. Incandescent gases under normal conditions give a spectrum of a very different character. It consists of a dark background crossed by bright lines variously distributed, as though a continuous spectrum had been chopped into small pieces. Each line corresponds to light of a definite wave-length, and as such it is usually identified in Ångström units, thus we may have the line 4862 A or 5896 A. So that whereas an incandescent solid emits lights of all wave-lengths gases only emit some. A gas such as oxygen or nitrogen can be made incandescent by an electric discharge in a tube with the gas at reduced pressure. A substance normally solid or liquid can be rendered gaseous by heat when it, too, will give a bright-line spectrum. The third kind of spectrum, the absorption, is obtained when white light on its way to the spectroscope passes through a gas at a lower temperature. The spectrum now is of the Frauenhofer type, a rainbow background crossed by black lines. The lines are in the same positions as the bright ones would be, in fact, if the white light is removed the lines show bright on the now dark background. This is called "reversing" the line. The gas cuts out, or absorbs, the same wave-lengths from a continuous source that it would emit on its own account. With any given substance the lines are the same as regards their intensities and distribution whether bright-line or absorption. It must be understood that there are many properties of spectra, spectral types, spectral series that can have no place in this account. For these the reader must consult more technical works.

No two substances under similar conditions give

the same spectrum. A person may be recognised by his appearance, his dress, or his signature. To many a bank official a man is only known by his signature. We may regard the spectrum of a substance as its signature. In its ordinary incandescence it is "scrambled" just as wireless telephonic speech can be scrambled to render it unintelligible to the unauthorised listener, the order of the words being restored by the authorised receiver. So, too, the spectroscope unscrambles the light of an incandescent substance and arranges the wave-length lines in orderly fashion so that they can be recognised.

So far we have dealt with the visible spectrum only. Using the photographic plate, which is more sensitive to the short than the long wave-lengths, the spectrum is found to extend far beyond the violet into a region known as the "ultra-violet" to which the eye is blind. Here, too, are series of lines similar to those in the visible spectrum which are recorded and of which valuable use is made. At the other end of the spectrum, the red end, is another extension invisible to the eye but detectable and measurable by instrumental means, known as the "infra-red." This, too, has its series of lines.

Thus we see that the spectroscope examines the light presented to it, light in the widest sense of the term, invisible as well as visible; sorts it out, disentangles it, laying its components neatly side by side so that their story can be interpreted. The validity of the conclusions we reach depends upon whether we interpret aright.

Some uses of the Spectroscope.

Since the spectroscope only requires the light emitted by a subtance which may be near at hand or billions

of miles away, it was quickly taken up by the astronomer. To-day it is one of his most useful instruments, has given rise to a special branch of the subject and a body of experienced men who are specially trained in its use. A telescope is employed, a spectroscope of special design attached to the eyepiece end and the spectrum photographed.

The sun and the majority of the stars give a spectrum of the Frauenhofer pattern, a few stars and some nebulae have bright lines. The sun has lines of most of the elements found on the earth, but since some of these are very refractory the temperature must be very high for them to be gaseous, much higher than anything we can produce on earth. The planets can give us no information about their composition for they are not self-luminous and merely shew a spectrum of sunlight. In many parts of the sky hazy patches of light are to be seen, some with the naked eye but many thousands with telescopic aid. As telescopes became improved some of these were seen to be large numbers of stars grouped together in clusters, and it was thought that perhaps as telescopic power increased all would prove to be star clusters. The spectroscope has shewn this not to be the case, for some of the nebulæ show bright lines and are undoubtedly gaseous and attenuated, very different from starlike.

A modern well equipped observatory is not merely a place where telescopes are installed. It is also a physical and chemical laboratory with an efficient staff trained to reproduce as far as terrestrial conditions will permit processes taking place in the heavens. Combining such observations with the information provided by the stars themselves through the spectroscope much has been learnt about star conditions and composition.

The progress in this direction in recent years is truly astonishing, for it must be remembered that a star is in a sense broadcasting a wireless message in cypher and the astronomer has had to discover how to detect the message and also the key to the cypher. In many cases a key has been found that will fit but it sometimes happens that when the cypher is decoded the message is in a language that is imperfectly known. That is why there is general agreement in the astronomical world on many points but not on others. It is not the observation but the interpretation that invokes discussion.

Chemical and physical experiment shew that as a rule heat tends to simplify a body. Compounds are broken down to simpler components by heat. Sometimes the breakdown is only temporary and the components re-combine when the heat is removed. This is known as "Dissociation." Sometimes the breakdown is of a more permanent character and the components do not re-combine easily. Compounds break down into their separate elements, then the elements break down from molecules to atoms. The question arises "How far can this decomposition proceed? Will a still further rise of temperature decompose the atom itself into its components? And if so, what are these?" We know there are protons and electrons, we hear, too, of neutrons, positrons and neutrinos, what else is there? We are handicapped because the highest temperature we can produce on earth is that of the electric arc or the condensed electric spark, which does not reach much above 4,000°C. In the sun and stars much higher temperatures exist, certainly many thousands of degrees higher, and according to some authorities millions of degrees in the interiors. What may happen at these temperatures we do not know, we can only conjecture, but there are

so many workers engaged in the task of observing and recording and interpreting that evidence is accumulating that may serve to solve present uncertainties.

Some stars have a red colour, their spectra have many lines, some those of compounds, therefore it is concluded that they are not very hot—celestially. Others are brighter, more golden in colour, with a less complex spectrum, suggesting a higher temperature; the sun is of this type. Others again are very bright, silvery white, with spectra shewing few lines, and they are of the lighter elements, Hydrogen, Helium and Calcium; these are supposed to be the hottest of all. Thus the stars can be arranged in a series with the relatively cool red ones at one end and the hot white ones at the other. Not only that, but certain peculiarities of the lines indicate whether the temperature is on the up-grade or the down-grade or stationary, so our series now becomes doubled, with some stars growing hotter and others cooler. Considerations of another kind lead to the conclusion that the up-grade stars are younger than the down-grade ones and also more bulky—not more massive but puffed out as it were. If these conclusions are correct a star starts its life as a young giant, passes through maturity less bulky but intensely hot, and then into old age as a low temperature dwarf. And then what? As it cools down below the point of luminosity what becomes of it? Even on this the spectroscope has something to say as will be seen later. Assuming that the spectroscopic message is being interpreted aright a star after it has cooled down below its temperature of incandescent visibility still exists and plays its part in the scheme of nature. There are many who hold the opinion that there are probably as many dark stars as lucent ones, that is, there must be thousands of millions of them.

The detection and measurement of radial motion.

There is one thing that modern scientific investigation shews very clearly and that is the general existence of motion in the inanimate world. Molecules of a gas in an enclosed space are in rapid motion as also are those of so-called still air in a room. The atoms within a molecule, the electrons and protons that constitute an atom, are all in rapid—and orderly—motion. The heavenly bodies, the sun, planets, satellites, comets are all observed to be in orderly motion. The stars, too, when observation over long periods is made, are found to take part in this universality of motion. The use of photography, enabling pictures to be compared after long intervals of time, has played a very important part in this work. But because the stars are so very far away very careful measurement is required to detect and measure the movements. Suppose the movement is in the line of sight directly towards or away from the observer, then obviously the photographic plate will shew no change of position. It might very well be thought that here is an insoluble problem. Think for a moment of a straight road two miles long with a motor car at the distant end at night with its head lights lit and facing an observer. It would be impossible, by observing the lights alone, to be sure whether the car is stationary or moving. How hopeless it would seem to attempt the solution of such a task in the case of a star billions of miles away! But with the spectroscope by the application of "Doppler's Principle" it can be done. A simple illustration of the Principle may be useful here. It is common knowledge that when an express train with the whistle sounding rushes past us through a station there is a marked drop in the pitch of the whistle. We notice the change of pitch in the

case of sounds from all rapidly moving vehicles. Let us consider the reason. The pitch of a sound depends on the number of waves of air reaching the ear per second; if this number is 256 the sound is the middle C of a piano, twice this number would give the octave higher; half the number would give the octave lower, and so on. When a sounding body is rapidly approaching the waves become more crowded together by an amount depending on the speed of approach, that is the frequency is increased and the pitch is raised. Therefore all the time the body is approaching at uniform speed the pitch of the sound is above its true pitch. With a receding sound the opposite effect is to be noted, the waves are stretched out, the frequency is lowered and all the time the sound is audible it is below the true pitch. If the change of pitch can be accurately measured, the velocity of sound in air being known, the speed of approach or of recession can be calculated. Such is "Doppler's Principle." Since light in its optical aspect behaves as a wave the Principle will apply to it. In sound change of frequency produces change of pitch detected by the ear, in light change of frequency produces change of colour detectable by the eye. The lowest frequency gives red, the highest violet; with the other colours in between, each wave-length corresponding to a definite colour and *in a spectrum to a definite line with its position accurately indicated in Ångström units.* The spectrum of a rapidly approaching light will therefore have all the lines displaced *towards the violet end*, that of a receding one will have them displaced *towards the red end.* If comparison can be made with the spectrum of a stationary light and accurate measurement of the displacement made, knowing the velocity of light, the speed of the luminous body can be calculated. As the speed of light is so great

only those sources of light moving with very high velocity give a measurable displacement. As will be understood, the task is one of extreme delicacy and everything in connexion with it requires very great care, but the staffs of the world's observatories have become expert with practice in achieving the seemingly impossible.

Briefly, the method is this: attention is directed to the line of a particular element—say iron. The telescope with its spectroscopic attachment is directed to a star and its spectrum photographed. At the same time iron is vapourised by an electric arc in the observatory and its light directed to the spectroscope in such a way that the two spectra are on the same photographic plate and slightly overlapping. Thus the iron lines from the two sources can be compared and any displacement measured. This is merely a brief and incomplete account of what is done but it gives an idea of the method. Results obtained shew that stars are moving *in the line of sight*, some approaching, some receding, with velocities of hundreds of miles a second. The conclusion is thus reached that there is no such thing as a "fixed" star but that they are all in headlong flight in all directions and it is only their immense distances from us that prevent our noticing it. The movements are relative because the sun, which is a star like the rest, is also moving at a terrific speed, compared with which a rifle bullet in flight is merely strolling along, and is carrying us with it. But it is possible to disentangle the various movements and produce some sort of order out of apparent confusion.

Another difficulty that has been solved is that of the rotation of Saturn's Rings. Saturn is one of the giant planets, about 800 times the size of the Earth. He is attended by nine or ten moons and has a very striking broad, flat, luminous belt surrounding

him, so that in a photograph he looks rather like a Christmas pudding on a plate. The luminous belt is rotating, but how? Like a wheel? If so, the outer edge will have to move more quickly than the inner, just as the rim of a wheel moves more quickly than the hub—it has further to go and has only the same time in which to do it. When spectra of the outer and inner edges of the rings are observed the displacement of the lines shews that the inner edge is moving more rapidly than the outer. Therefore it is *not moving like a wheel.* The conclusion is that the rings consist of a crowd of tiny moonlets each travelling round the planet on its own account in the same way as our Moon travels round the Earth. Only the spectroscope is capable of giving us this information.

The Solar System is a system in motion, but only one member of it, the Sun, is self-luminous. There are large numbers of moving systems in the heavens consisting of several luminous members. If they are so placed that we get a "full-face" view of them telescopic observation over a sufficiently long period will disclose them. If however they are edgewise-on to us the telescope alone is useless. There are many instances where the spectrum of what is apparently a single star shews lines at times in pairs. This is interpreted as being due to a system of two stars so far away that the telescope is unable to separate them, with their plane of motion end-on to us so that each star is sometimes moving towards us and at others away. This shifts the lines on opposite sides of the normal, thus causing the doubling. Such stars are known as "Spectroscopic binaries."

Many stars shew differences of intensity in their light and are known as "Variables." Some of them vary with striking regularity. One of these well-

known from ancient times is Algol, the Demon Star, and is easily observed with the unaided eye, being well placed in the winter months. Normally it is about as bright as the stars of the Great Bear (The Plough). At a given moment it will begin to decline in brightness and in about 4 hours will have faded to the very limit of naked-eye visibility, remaining thus for about 20 minutes. Then it begins to brighten up and in about 4 hours will be of normal brightness again, remaining so for about 2 days 13 hours, when it goes through the same changes again. This curious behaviour of the wicked star that winks its eye was long a mystery until the spectroscope cleared it up. Doppler's Principle again shews a shift of lines during waning and waxing leading to the conclusion that here, too, is a star system consisting of two stars, one being bright and the other comparatively dark, moving in a plane that is end-on to us, so that at each revolution the dark one partially eclipses the bright one, causing the variability changes. Algol is therefore an eclipsing variable and is only one of many such.

An aviator at a high elevation looking down at a blazing furnace will see an undetailed glare. The glowing interior, the rising flames and incandescent vapours are all mingled together. We are in much the same position when we look at the sun. The conditions at different levels, the movements of the various parts are indistinguishable. The spectroscope has done much to disentangle this mass and to enable us to get some information of what is going on. Using a large slit and moving the sun's image across it an examination of it can be made in sections and the whole spectrum story built up. Radial movements indicating forces of great intensity especially in the neighbourhood of sunspots are

in this way detected. Cyclonic storms of terrific violence are evidently of commonplace occurrence in the sun.

An important development of the spectroscope, largely due to Hale, of Mount Wilson, and now in use in all the large observatories of the world, is the "Spectroheliograph." A description of the instrument cannot be undertaken here, but briefly stated it is a double spectroscope, having a second slit, which by a carefully adjusted moving mechanism can be restricted to any single particular line of the spectrum from the first slit. When we look at the sun in the ordinary way we see it in light of all the wave-lengths mixed together. If we could be blind to all the wave-lengths except one we should see it in the light of that wave-length alone. If that wave-length happened to be a Hydrogen line we should see the sun only as incandescent Hydrogen and should be blind to everything else. If it happened to be a Calcium line we should see the sun as incandescent Calcium only. That is what the spectroheliograph does. Any particular line can be chosen and the sun photographed in that light alone. Whereas the earth's atmosphere extends only a few hundred miles from the surface, that of the sun reaches many thousands of miles and is incandescent. In the higher parts hydrogen is found, at lower levels there is Calcium, with other elements at other levels. By keeping to the light of a particular element therefore knowledge of what is going on at different solar levels can be obtained.

Another modern use of the spectroscope is for the measurement of star distances. An inaccessible object can have its distance measured if it can be observed from two different points and its apparent change of position accurately estimated. The value of

the method depends largely on the distance between the two points of observation. For an object a few miles away a baseline of a few yards would suffice. For the Moon the Earth's diameter—8,000 miles—will serve, but for a star a much longer baseline is necessary. In our annual journey round the sun we are at an average distance of about 93 million miles from it. Therefore in six months, say from June to December, our positions in space are separated by 186 million miles. If we observe a star at intervals of six months we are doing so from points 186 million miles apart. Even a huge baseline like this is far too small for any but a few hundreds of the many millions of stars, *and we cannot get a longer one.* Another apparently hopeless problem has been solved by the spectroscope. It has been found that the intensities of certain lines are a measure of the "intrinsic" brightness of an incandescent body. The "apparent" brightness can be measured as we measure that of a candle flame or any other light, and the two are related by the distance separating the light and the observer. Here are three things, two of which can be measured and the third, the distance, can be calculated from the other two. The result has been astounding. We knew the visible Universe to be immense but we had no idea it reached out into space to such an incomprehensible distance.

The X-rays, like light, consist of many wave-lengths mingled together. They too can be sorted out and arranged in the form of a spectrum but not with the ordinary type of spectroscope. The spectra obtained are of special interest in extending our knowledge of the constitution of Matter and will be referred to in a later chapter.

All this has resulted from the simple observation of a beam of light passing through a hole in a shutter!

CHAPTER VI

RADIUM AND RADIOACTIVITY

THE 19th Century saw the two sciences, Chemistry and Physics, being slowly but surely built up by the labours of a host of patient investigators. The foundations were carefully laid and the superstructure tested bit by bit. In the later years of the century the Chemist and the Physicist joined forces, the new science of Physical Chemistry being the result. Such care was taken, every new notion so drastically tested, that there seemed to be no room for error. Chemical action and physical forces could bring about various changes in substances, but whatever the changes they were regarded as merely re-arrangements of the atoms and molecules of which they were composed. The atoms themselves remained unchanged and unchangeable, they were the bricks with which everything was built. They could be moved into different positions or built into different patterns but they could not be broken. You must use a whole atom or none at all. It was the indestructible entity. Then in 1898 there occurred a sort of scientific earthquake. The structure so carefully erected during the century was so severely shaken that it seemed to be in danger of toppling over. The very foundations seemed insecure and the work of a century or more of little value. The cause of this alarm was the discovery of Radium, an element unlike any previously known, possessing inexplicable properties.

Its discovery was in a sense an outcome of that of the X-rays. It will be remembered that two of the properties of these rays are the production of fluorescence

in certain substances and the ability to affect a photographic plate like light. Now fluorescence is a property long known. Some substances will fluoresce after exposure to light, especially ultra-violet light, or after electric stimulus of some kind. Others such as phosphorus will do so under chemical action, others again as a result of bacterial action. In each case one of the observed effects is the production of a glow in the dark. Practical use has been made of this in the luminous matchbox which is coated with a fluorescent material such as calcium sulphide. When the fluorescence associated with the production of X-ray was found to be accompanied by the power of affecting a screened photographic plate it was thought that perhaps all fluorescence could behave in the same way. In 1896, shortly after Röntgen had discovered the X-rays, Henri Becquerel decided to repeat some experiments he had carried out many years before with certain Salts of Uranium which he had found to possess fluorescent properties. The compound contained in a glass tube was exposed to sunlight and afterwards placed near a protected photographic plate for several hours. On development the plate was found to shew a distinct impression of the salt and tube. This seemed to point to fluorescence of this kind being accompanied by rays of an X-ray character. A fortunate chance however led to a different conclusion. On a certain occasion, after waiting for bright sunshine which failed to appear, the tube and plate were put aside to await a more favourable opportunity. After several days this plate on development shewed a similar impression. This suggested that the property of emitting penetrating rays belonged to the Uranium and that exposure to light and fluorescence had nothing to do with it. Further

experiments of a conclusive kind confirmed this view.

Becquerel's announcement of these results in 1896 aroused a good deal of interest. Why should Uranium behave in this curious way? At this stage Mme. Curie, the wife of Prof. Curie, joined in the investigation. Being a chemist, she naturally regarded the problem from the chemical point of view rather than the physical. A first step was to ascertain if any other elements besides Uranium possessed the same power. Of all the known elements, over 80 in number, there was found to be only one other able to behave in this way, that being Thorium. Both these elements are at the higher end of the list of elements, Uranium having an atomic weight of 238 and Thoriun of 232 (Hydrogen = 1). Having settled this point, the question arose whether the minerals from which the elements are extracted emit the rays. Experiment gave the remarkable result that they were *more active than the elements themselves.* Let us pause for a moment to consider what this means. Whatever the mineral may be it contains other things besides the element concerned. If the emission of the rays is due to the element, as it was presumed to be, the mineral ought to be less active. Instead *it was more.* The inevitable conclusion therefore was that there was something else in the mineral responsible for the ray emission and an intensive search was made for it.

There are many sources of Uranium, but the mineral eventually selected was Pitchblende. It is generally found associated with ores of tin, some very rich samples being found at the Trenwith tin mine near St. Ives, Cornwall. The richest specimens were found in Bohemia (Czecho-Slovakia) then owned by the Austrian Government. A fairly large quantity of this having been obtained, a chemical analysis was made of it, the various

elements present extracted and separately examined, this time not by photographic methods but by electrical, which were capable of greater precision. Of the elements found, Uranium, copper, tin, iron, lead, bismuth, barium and many others, the only ones shewing the power of emitting penetrating rays—which we will now call "radioactivity" were Uranium, Bismuth and Barium. Bismuth is a very well known element, being in general use in the Arts, Manufactures and Medicine. It is obtained from minerals containing a much greater proportion of it than Pitchblende and it is *not radioactive.* Yet here was a specimen of it undistinguishable from ordinary Bismuth by any chemical test that could be applied and possessing in addition to the usual properties the extraordinary one of radioactivity. There must be some reason, what was it? The product obtained was a salt of bismuth in the form of small white crystals. Now there is a general rule about crystals known as "Isomorphism," in obedience to which the crystals of any compound have the same shape. They may differ in size, but if they have crystallised freely, undistorted by any action such as pressure or overcrowding, their shapes are precisely alike. Examining a small heap of the crystals, Mme. Curie noticed some of the wrong shape. With infinite pains she picked out the oddly-shaped ones and so separated them into two heaps, the larger of the normal shaped ones and the smaller of the oddly-shaped ones. The latter were found to be *intensely radioactive*, the former were inactive. Here then was the secret. Something was evidently present along with the Bismuth, chemically indistinguishable from it but crystallising in different form and very radioactive. In honour of her native country, Poland, Mme. Curie named this substance POLONIUM.

Turning now to the other radioactive constituent of the Pitchblende, Barium, similar facts were noted. Barium is well known and its compounds widely used but as usually obtained is not radioactive. In this case also, abnormal crystals were to be seen. Having ascertained that there was also a difference of solubility, separation was effected by fractional crystallisation, a much easier method than picking out by hand. Here again two portions were obtained, one like any ordinary Barium compound and inactive, the other intensely radioactive. Here, then, was a substance that could not be distinguished from Barium by any known chemical test but was not Barium and was nearly a million times as radioactive as the original mineral. The name given to this was RADIUM, the discovery being announced in 1898. The yield was very small; from 2 tons of Pitchblende only $\frac{3}{4}$ of a grain was obtained. Its appearance is not remarkable, small white crystals somewhat like common salt, which gradually become discoloured, eventually assuming the colour of coffee.

The discovery was something like the unearthing of a criminal by a detective. Clues were looked for and when found carefully followed. Cross trails were avoided, useless material eliminated, until finally a piece of research which for care and patience has not been surpassed was crowned with success.

As the remarkable properties of Radium became known they were regarded with amazement not unmingled with dismay. Nothing before had been known to behave in such an extraordinary fashion. It was a sort of outlaw. For over 100 years new elements, as they were discovered, were found to fall into line and obey the general laws that had been patiently built up as the result of long and careful observation. Not

a single one had deviated from the path of elemental rectitude. But Radium was not bound by such laws. Science was faced by two alternatives—either its laws were at fault or elements possessed properties not previously taken into account. The five years from 1898 to 1903 were years of uncertainty, of suggestion and counter suggestion, but in the latter year, largely owing to Rutherford and Soddy, the enveloping darkness gave way to a gleam of daylight. To-day, as we look back, we are inclined to wonder which was the greater, the discovery of the first radioactive element or the explanation of radioactivity in general.

The properties of Radium.

1°. It is related to Barium and is chemically indistinguishable from it.

2°. It is a heavy element with an atomic weight of 226 (Hydrogen = 1, Lead = 207).

3°. It emits light, glowing feebly in the dark like a glow-worm.

4°. Fluorescent bodies such as barium platino-cyanide, zinc blende, willemite, and many precious stones give out light when in its neighbourhood.

5°. It gives out heat, being always several degrees warmer than its surroundings. Its heat emission is such that it is capable of boiling its own weight of water every hour.

6°. The air in its neighbourhood is ionised, that is, becomes electrically conductive.

7°. It emits rays of an X-ray character but much more penetrating.

These are certainly unusual properties, but what was very unsettling was that all this outpouring of energy

seemed to be gratis. We are accustomed to many transformations of energy and in all our experience the appearance of any form of energy is accompanied by the disappearance of some other kind. But this appeared to be a free gift, something for nothing. Measurement failed to detect any loss.

During several years an intensive search was made for an answer to the puzzle, and in 1903 Rutherford and Soddy found one. Atoms of Radium are *unstable and liable to break asunder, some of the internal energy escaping in the process.* It was found that the rays emitted were of several kinds, three certainly, possibly more; which are labelled α-rays, β-rays and γ-rays.

The α-rays are atoms of Helium positively electrified and travelling at speeds which may reach as much as 12,000 miles a second.

The β-rays are the same as Crookes' Cathode rays, i.e. electrons negatively electrified and travelling at speeds which sometimes get very near that of light.

The γ-rays are true X-rays, of short wave-length and very penetrating.

The disintegration is something like this—two atoms of Radium may have been in close association for centuries and nothing out of the ordinary has happened. Suddenly one of them, for no apparent reason and without any external stimulus, explodes. It is a true explosion, for a bullet is expelled and the atom recoils as a rifle does, but whereas no explosive we can produce can expel a bullet with a greater velocity than about half a mile a second the α-ray travels at 20,000 miles a second! Think of the energy necessary to do that. In firing a bullet all the energy in the cartridge is expended, the rifle must be recharged before a second shot can be fired. Not so the Radium atom.

Having lost its α-particle it is no longer Radium, it is now "Radon" and is 4 units of weight lighter. Radium has an atomic weight of 226 but Radon is only 222. After a while it does the same thing again for no apparent reason, again firing an α-bullet, recoiling and losing 4 units of weight. The atom now, with a weight of 218, is called "Radium A." Five times this can happen with a loss of 4 weight units each time. Five times also an explosion occurs with the expulsion of a β-bullet negligible in weight but travelling at a velocity which may reach 160,000 miles a second! What an enormous store of energy the original atom must have possessed, for even now it may have plenty left although it is incapable of spontaneous disintegration.

Radon, the first disintegration product of Radium, is an invisible gas closely related to the Argon family of gases found in the atmosphere. A close study of its behaviour by Ramsay and Soddy in 1904 led to the definite conclusion that the α-particle is an electrified atom of Helium, which becomes ordinary Helium on losing its electric charge. Thus, for the first time in the history of the world, we have direct evidence of "*transmutation*" *of an element*. During many years in the Middle Ages alchemists had been trying to transmute base metals into precious ones without success. Dishonest claims of success brought alchemy and alchemists into disrepute, but if they had only known it something of the kind was going on all around them. There is, however, a difference; radioactive transmutation is a natural process, not one of human agency and nothing we can do can check or modify it. If an atom of Radium wants to explode nothing we can do can prevent it, and if it doesn't want to break up we cannot make it. High or low temperature,

pressure, or any other forces we can apply make no difference.

So far we have not referred to the other element Thorium that Becquerel and Curie found to be radioactive. It too behaves in the same way and for the same reason, giving rise to a series of different bodies sometimes ejecting an α-particle and losing 4 units of weight, sometimes a β-particle with negligible loss. Six times an α-bullet is expelled until finally with Thorium D the atom is no longer capable of spontaneous break-up. A gaseous member of the series similar to Radon and named "Thoron" was discovered by Rutherford in 1900.

Another important radioactive substance named "Actinium" was discovered by Debierne and Giesel. It too gives rise to a series of products and after the emission of 5 α-particles becomes stable as Actinium D.

Boltwood made the interesting discovery of "Ionium" which has proved to be the parent of Radium.

We have seen in a previous chapter how exceedingly small an atom is and in this account of radioactivity we have been considering the changes occurring in individual atoms. But the smallest visible bit of any radioactive substance contains a prodigious number of atoms and a certain proportion of them will be passing through the changes indicated at any one time. Since the loss of an α-particle means the loss of 4 units of weight the substance must in course of time shew a measurable loss. Some break up rapidly and therefore have a short life, others break up slowly and are long-lived. It was because Radium belongs to the latter class that its behaviour was not understood for so long. With the discovery of the

short-lived products it became possible to make accurate measurements, detect the precise nature of the changes and find the law governing them. It has been found that whatever quantity of Radon we start with, in about 4 days it is reduced to one-half, in another 4 days the remainder diminishes to one-half and so on until no more is detectable. Other short period products behave similarly but with different time intervals. This time-interval is known as the "Half life period," or simply "The Period." From the general law obtained by a study of the short period bodies the periods of the long-lived bodies have been calculated. Below we give a table showing the more important of the radioactive bodies with their periods. Chiefly those disintegrating with the emission of α-particles are shewn here; for a complete list more comprehensive works should be consulted.

Radioactive Elements with their Periods :

Element	Period	Atomic Weight
Uranium I	5,000 million years	238
Uranium II	1 million years	234
Ionium	? ? ?	230
Radium	1,600 years	226
Radon	4 days	222
Radium A	3 minutes	218
Radium B (β-only)	27 minutes	214
Radium C^1	20 minutes	214
Radium C^2 (β-only)	Fraction of a second	210
Radium D (β-only)	25 years	210
Radium E (β-only)	5 days	210
Radium F (Polonium)	136 days	210
Radium G (Lead)		206

Element	Period	Atomic Weight
Actinium (β-only)	$13\frac{1}{2}$ years	227
Radioactinium	19 days	227
Actinium X	11 days	223
Actinon	4 seconds	219
Actinium A	Fraction of a second	215
Actinium B (β-only)	36 minutes	211
Actinium C	2 minutes	211
Actinium C^2 (β-only)	5 minutes	207
Actinium D (Lead)		207
Thorium	16,000 million years	232
Radiothorium	2 years	228
Thorium X	$3\frac{1}{2}$ days	224
Thoron	1 minute	220
Thorium A	$\frac{1}{7}$ second	216
Thorium B (β-only)	10 hours	212
Thorium C	1 hour	212
Thorium D (Lead)		208

It will be observed that the final product in each case is Lead. The question whether all the lead in the world has been derived in this way is an interesting one; it is possible but does not seem probable, there is not sufficient evidence to decide the point. There are nearly forty radioactive elements all derived from the three parent bodies Uranium, Thorium and Actinium. It has been suggested that the two latter have been derived from Uranium and that it too had its origin in a still more massive element which has disappeared by disintegration during past geological ages. Only time and further discovery can settle a question so difficult of solution, but the fact that it

is seriously being considered shews the trend of modern scientific thought.

Does radioactivity really end with Lead? Some of the lighter elements have shewn signs of it, particularly Potassium and Rubidium. Methods of detection have become so sensitive and the difficulty of chemical separation are so great that the effect observed may be due to contamination with a minute amount of one or other of the heavy radioactive bodies. There is however definite opinion in favour of the view that disintegration may occur in the lighter elements. It is true that radioactivity can be "induced" in a light element by bombarding it with high velocity particles as was announced in 1934 by Joliot and I. Curie, but this cannot be classed as natural radioactivity.

Radioactive bodies must be handled with great care for the rays they emit have a serious effect on living tissue. This has led to their use in the treatment of cancer and other ailments. Radium Institutes and Clinics have been established all over the world to try its effect in obstinate cases that will not yield to other treatment. Radium Chloride or Bromide is used, enclosed in a suitable case, introduced into the diseased tissue and left there for a suitable time. Bombardment by the rays goes on and then the capsule is removed. In some instances marked benefit results, but medical opinion is very divided as to the value of the treatment. The great cost of the Radium is a drawback and it is only by pooling supplies that the work can be carried out on any large scale.

Although radioactive minerals are widely distributed over the world the yield is very small. Much of

our supply has come from the Belgian Congo, but the announcement has been made that a very large store of rich supply has been discovered in northern Canada. It is in a place rather difficult of access but the discovery may mean a very much needed reduction in cost.

The high velocity particles from some of the short-lived bodies, such as Radium C, have been used by Rutherford and his co-workers in the Cavendish Laboratory at Cambridge as projectiles to bombard the atoms of elements in an attempt to break them up. A reference to this work will be made in a later chapter.

CHAPTER VII

COAL AND ITS PRODUCTS

WHATEVER views we may have about the early history of the Earth there is no doubt that there was a time in the far distant past when climatic conditions were very different from any existing to-day. Intense humidity, high temperature, torrential rains, all combined to encourage profuse vegetation, chiefly of the non-flowering type although not exclusively so. With the seasonal changes vast quantities of vegetable matter, leaves, twigs, branches and tree trunks cast down by winds of hurricane violence that were prevalent deposited on the swampy margins of large inland lakes and wide shallow river estuaries soon formed peat bogs of great extent in which the vegetable material underwent slow decomposition. Earth movements also played their part; a depression would cause the bed of vegetation to be submerged and quickly overlaid by mineral matter carried down by streams in flood. The calcareous remains of the organisms living and dying in the waters added their quota to the rest. Later earth movements might cause an elevation above the general water level and before long a soil would form and another vegetation develop. This might happen several times so that beds of vegetable matter partially decomposed and completely changed became sandwiched between beds of mineral matter. Pressure and heat completed the change, the vegetation became coal, the mineral matter became rock with the result that to-day we find coal in "seams" of various thicknesses from a

few inches to 50 feet or more separated by layers of sandstone, limestone, conglomerate, shale or other rocks.

The necessary conditions for the production of coal have prevailed during different Ages in different parts of the world although the bulk of it belongs to the "Carboniferous Age," especially in the British Isles. There is abundance of evidence in support of this view of the formation of coal. Fossil remains shewing the complete details of leaf, frond and twig are found in the rock layers separating the seams, whilst in many cases whole trunks of trees are also found, some standing upright with their roots embedded in the shale—the hardened mud of the swampy ground in which they grew—and their stems reaching into the coal itself. The coal itself has become so changed during its formation that the details of its vegetable structure have disappeared except in some of the younger brown coals or "lignites." Fossil shells both of fresh-water and marine organisms are found in abundance, adding further evidence to the views briefly outlined above.

Subsequent contraction of the earth has caused the strata to be folded, twisted and contorted, bringing some of the coal seams nearer the surface so that by denudation of the overlying rock they become disclosed, distorting others to far greater depths. Consequently in some districts the coal can be obtained by simply cutting into a hillside, whereas in others a shaft has to be sunk to a depth of half a mile or more. Such then is the origin of our coal, our raw material for the subject we are to consider.

In this country we raise annually over 200 million tons of coal. Nearly half of this is burnt in domestic

fires, industrial furnaces and such like. Probably about 10% is used for gas making, the remainder being used for metallurgical purposes and for export.

As a fuel it had to struggle for recognition. In 1239 a Charter was granted to Newcastle by Henry III permitting its sale, and it was introduced into London under the name of "sea cole." Either it must have been of poor quality or imperfectly consumed for a petition was made to Edward I protesting against its use because it was a "public nuisance." Queen Elizabeth issued a proclamation against its use during the sitting of Parliament owing to possible injury to the health of the Members! Another petition against its use was presented in 1649. The prejudice against it was evidently very great.

Before we consider its use it may be well to see something of its composition. Its chief component is Carbon, either alone or in complex combination. Hydrogen, Oxygen and Nitrogen also enter into it in various combinations. As Carbon is by far the most important element we consider it alone in the following table.

Percentage of Carbon.

Typical woody fibre	50%
Peat	54%
Lignite	66%
Bituminous Coal	77%
Cannel Coal	81%
Anthracite	90%

Seeing the steady increase in percentage of Carbon as we pass from wood to anthracite it is only natural to enquire if this points to a steady progression of development. Whether for instance anthracite has

passed through the earlier stages or owes its special characters to some other cause. On this point expert opinion appears to be divided. Some hold the view that fractures in the strata due to its folding have allowed the more volatile matters to escape and in this way given the anthracite its valuable smokeless character. Others consider that the nature of the vegetable matter was different and that also perhaps the degree of pressure and temperature and duration of their action were not the same. Be that as it may the different varieties exist and each has its especial value. In this country there is not very much lignite; it is more generally found on the Continent, in U.S.A. and in the Colonies.

The Destructive Distillation of Coal.

The term "destructive distillation" although long in use is not quite accurate as a precise description of what takes place, and is being displaced by the term "Carbonisation." This again is qualified according to temperature, that conducted at temperatures of 900° C. or more being known as "High-temperature Carbonisation, while that below 400° C. is termed "Low temperature Carbonisation." True distillation is the conversion of a substance into vapour by heat followed by the condensation of the vapour by cooling, the chemical composition of the substance remaining unchanged throughout the operation. The change of water into water vapour and its condensation to distilled water is a case in point. When coal is heated out of contact with air, vapours are produced, some of which condense on cooling, but the coal is not reproduced, the changes are permanent, hence the term "Destructive."

That an inflammable gas was obtainable from coal

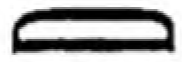
was known at the end of the 17th Century, but merely as a scientific curiosity. That a tar was also produced that had useful qualities for outdoor purposes was taken advantage of a century later by the Earl of Dundonald at Culross Abbey. But it was not until 1798 that William Murdoch used the gas as an illuminant, first at Redruth and later at Soho, near Birmingham.

In spite of the fact that tallow candles with "snuffy" wicks and oil lamps burning vegetable oils such as colza—mineral oils for such purposes being unknown—were the chief illuminants, the gas had a long struggle before it was accepted for general use. A well-known London theatre still stuck to the old method of lighting till about 1840. For indoor purposes it was considered dangerous and even for outdoor it was regarded as rather risky. A few lamps were tried in London in 1809, but another four years elapsed before it came into more general use for street lighting.

At first the tar was a troublesome and practically valueless by-product, a good deal of it being thrown away. Gradually its value as a protecting paint for outdoor purposes was recognised. Experience shewed that concentration by boiling improved its protective qualities so it was boiled in open pans. A serious accident caused by someone approaching some boiling tar with a light led to the discovery that inflammable vapours were given off in the process, so the pans were covered and the vapours led away and cooled. A spirituous inflammable liquid was thus obtained, known as "tar spirit," which had valuable solvent powers for resinous substances and was therefore useful for varnish making. As it would also dissolve indiarubber, Mackintosh of Glasgow used it for waterproofing fabrics, hence the name "Mackintosh" for a rainproof coat.

Much later a special lamp was devised for use with a purified naphtha for outdoor illumination. Gradually the value of the products from the tar became known until to-day the Coal Tar Industry has become one of supreme importance.

High-Temperature Carbonisation.

Suitable bituminous coal is washed, broken into small fragments and packed into retorts which have various forms. An early arrangement still in use in small gasworks consists of six or eight earthenware retorts each about 20 feet long and in section like a letter "D" lying on its side thus . These are built into a "bank" and heated either by coke from previous operations or by gas. Each retort is provided with a vertical exit pipe for the gaseous products and is closed by an airtight cover. The charging is done by hand. More modern retorts used in large gasworks are of iron, much larger and either inclined or vertical. The latter type is charged at the top by a self-acting mechanism, heated by gas and matters so arranged that by the time it has reached the bottom the coal has lost all volatile matter and is discharged as coke. This is the ordinary gas coke used for stoves and small furnaces. A special variety required for metallurgical purposes is obtained in another way and will be referred to later.

We will now follow the gaseous products during their subsequent treatment. In the heated condition in which they are produced, at about 900° C. they pass up the outlet pipe—the rising main—and bubble into water in another pipe—the hydraulic main. Here they are cooled and anything soluble in water is dissolved. From this they pass through a series of large pipes in

the open air—air condensers—and are still further cooled with further condensation. By this time the gas has been deprived of much impurity but still contains some that is removable by water provided it can come into intimate contact. For this purpose tall towers called "scrubbers" are loosely packed with some indifferent material such as coke over which water is sprayed and through which the gas is made to pass. The watery and tarry liquids from these various operation all flow into a receptacle called the "tar well." The gas still contains impurities, chiefly compounds of sulphur that must be got rid of to render the gas suitable for domestic purposes. This is done in the "purifiers," large tanks with shelves covered with oxides of iron and lime, over which the gas passes slowly. The gas now is sufficiently purified for use and passes into gasholders for storage. The purifying materials from the tanks by further treatment can be deprived of the sulphur, which becomes the crude sulphur of commerce, and used over again.

There are so far four main products of the carbonisation process—coal gas, watery liquor, tar, coke. It is important to stress the fact that these substances are not present *as such* in the coal. The elements of which they are composed are there but during the heating there is a general breaking-up followed by a reshuffling. Molecules are broken down and other molecules built up; there is a complete rearrangement of the elements present and new compounds produced. The various products are not extracted from the coal by heat alone, an exhaust pump exerts a pull, the consequent reduction of pressure having an effect on the nature and amount of the decomposition products. From 1 ton of coal the following can be obtained:

Gas . .	12,000 to 13,000 cubic feet
Tar . .	12 gallons
Gas liquor .	25 gallons
Coke .	1,500 lbs.

The gas is mainly a mixture of Hydrogen and Methane (Marsh Gas), with a smaller amount of Carbon Dioxide, Carbon Monoxide, Ethylene, Acetylene, Nitrogen, etc. A typical example would be:

Hydrogen	50%
Methane	32%
CO and CO_2	10%

The remaining 8% would be Nitrogen and various unsaturated hydrocarbons. The proportions vary considerably, depending on the temperature and other conditions of the carbonisation process.

In the days before Welsbach's invention of the incandescent mantle, when the naked flame was used, a certain amount of cannel coal was used to increase the illuminating power. Nowadays this is unnecessary, gas is produced with a high thermal value, light being obtained by means of a mantle. This means that water gas and producer gas, both with practically no illuminating value, can be added to the ordinary coal gas. The amount has to be limited because they contain a large amount of the highly poisonous Carbon Monoxide.

For metallurgical purposes such as the smelting of iron coke is required free from many impurities present in ordinary gas coke. Special care has to be taken in the selection of the coal and in its preliminary treatment. In some English coalfields such as those of Durham and Yorkshire the coking industry is an important one. Coke cannot be made without at the

same time producing gas and tar, but these are the waste materials of the industry. Until comparatively recently they were treated as truly "waste" materials and allowed to escape. Large coke-ovens built of brick, shaped like immense bee-hives and therefore called "bee-hive ovens" were packed with the coal, heated from below and all volatile matter, i.e., gas and tar provided with escape openings at the top. Other countries, notably Germany, realizing the wastefulness of the loss of such valuable materials, took steps to recover them. Coke ovens of a totally different type, known as "Recovery Ovens," were built enabling all the products to be retained. England has now followed suit and the old-fashioned bee-hive oven is rapidly being displaced. In this way large quantities of tar are now obtained. Unfortunately much of the gas is wasted, for even after providing for the needs of the colliery and its immediate district large amounts have to be burnt uselessly merely to get rid of it.

Low-Temperature Carbonisation.

It has been stated above that temperature determines the nature of the decomposition of the coal. When it is kept below 500° C. it is known as "Low-Temperature Carbonisation." Compared with high temperature methods the yield of gas is rather less than half, the coke is about the same but there is twice as much tar. It is on the coke and the tar that chief attention is centred. The coke is known as a "semi-coke," is not so hard as the ordinary kind, is more easily ignited and burns with a flame but without smoke. It is hoped that if it comes into general use much of the smoke nuisance in our large towns and industrial areas will disappear, with consequent benefit to health and

diminution of fog. It comes into the market under various names such as Coalite and Carbo-Coal. The tar has a very different composition from ordinary tar as from it can be obtained oils similar to those from petroleum. It is the possibility of our being able to obtain our oil supplies from our own coal instead of having to import it that lies behind the interest in low temperature processes. In spite of prospecting the British Isles have hitherto given little promise of oil supplies in paying quantity. On the other hand there is abundance of coal for which external markets are diminishing. If then it can in any way be made to yield oil for which there is an ever increasing demand, at a price that can compete with foreign petroleum oils it will have a good chance of emerging from the depression in which it has been for so long.

There is another way of obtaining oil from coal that does not depend on carbonisation; this is the "Hydrogenation" method. All the petroleum oils, petrol, paraffin oil, heavy fuel oils are "hydrocarbons," i.e., compounds of hydrogen and carbon. Hydrogenation consists in making the carbon of coal combine directly with hydrogen to form the required oily hydrocarbons. This is being done on a commercial scale which is predicted by many to provide a solution of the problem. Further reference will be made to this in the chapter on Catalysis.

The Products of Carbonisation.

We have mentioned above that there are four main products—gas, watery liquor, tar and coke. Of the coke we have nothing more to say and very little of the gas. The bluish flame of the gas cooker, gas ring or incandescent burner is familiar to everybody, but

few realize the extent of the indebtedness of the gas industry to Bunsen, who invented the burner known by his name soon after 1850. Its simplicity and efficiency are its great merits.

When a piece of lime is strongly heated in an oxy-hydrogen flame it is raised to a state of brilliant incandescence, known as limelight, used for optical lanterns and wherever an intense illumination is required. The much lower temperature of the Bunsen burner is incapable of raising it to the requisite condition. In the search for a substance that would become similarly incandescent at the lower Bunsen temperature Welsbach was fortunate in having at his disposal quantities of Monazite sand taken to Germany as ballast in ships trading with South American ports. These sands contained many of the "rare" elements whose properties were studied by Crookes in the '70's and '80's of last century. Two of them, Thorium and Cerium are used in mantle making. A muslin mantle is impregnated with a solution containing about 99% Thorium with 1% Cerium and strongly heated. The salts which had entered the pores of the muslin mantle now leave a white ash of the oxides of the two elements which is sufficiently tenacious to hold together but too fragile to handle. For transit it is dipped in collodion, which forms a protective skin and which is burnt off before use. The introduction of the mantle has revolutionised the gas industry by making it no longer necessary for the gas to attain to a high illuminating power, but to have instead a high thermal value. Gas to-day therefore is graded in "Therms" instead of "Candle-power."

For automatic control of the gas supply many forms of "Thermostat" are in use under various names. These depend on the different amount of expansion of

different metals when heated, or of contraction when cooled, varying the supply inlet of the gas. Another ingenious use of gas is for refrigeration. A mixture of Hydrogen, Ammonia and Water in a series of metal tubes under the influence of a very small gas burner undergoes a series of changes involving evaporation, condensation, and solution which results in a reduction of temperature under such conditions of control that it can be usefully and economically employed for preservation of food.

The Contents of the Tar Well.

The liquid in the Tar Well is in two layers, the lighter watery component at the top, the heavier dark coloured viscous one at the bottom. The upper portion on being drawn off smells strongly of ammonia. It is known as "Ammonia Liquor" and is the principal source of our supplies of ammonia and ammonium compounds. The ammonia derived from it when combined with sulphuric acid (Oil of Vitriol) gives Ammonium Sulphate, a valuable fertiliser for plant life. Combination of the ammonia with two other common acids, Hydrochloric (Spirits of Salt) and Nitric (Aqua Fortis) gives two other useful compounds Ammonium Chloride (Sal Ammoniac) and Ammonium Nitrate. All plants require Nitrogen for their sustenance, but although the atmosphere contains it in abundance they are unable to make use of it except in a few instances. The nitrogen must be in soluble form and taken in through the roots. It is for this reason that the ammonium salts which are very soluble are of such value to agriculture. As a general rule the necessary treatment of the ammonia liquor is carried out at the gas works.

The TAR contains a large number of different substances which boil at different temperatures. When this is the case they can be isolated by distillation, true distillation this time. When the mixture is heated the temperature rises until ebullition begins when it remains steady. If a suitable condensation attachment is provided the condensed vapour can be collected. Boiling now ceases and the temperature rises until the remaining mixture boils again. This is repeated as long as there is anything vaporisable remaining, the separate condensed portions being known as "Fraction 1," "Fraction 2," etc. The separation is not complete in one distillation because before the whole of any fraction is separated a small quantity of a higher fraction begins to be carried over. For more complete separation therefore the fractions have to be redistilled and it is often a matter of difficulty to get a fraction absolutely pure. For most practical purposes however redistillation gives fractions of sufficient purity. Some large gas undertakings carry out the distillation themselves, but the bulk of the tar is sent to the tar distiller for the purpose, and a good deal of British tar is sent abroad.

It is the general practice to separate the tar into 4 fractions. The first contains all that distils up to a temperature of about 210° C., the second that between 210° C. and 240° C., the third between 240° C. and 270° C., the fourth above 270° C. as long as distillation is possible. There is then left in the still a black viscid pitch. The tar has now been separated into:

Fraction 1.—Light Oils, not miscible with water and lighter than it.

Fraction 2.—Heavy Oil or Carbolic Oil, heavier than water.

Fraction 3.—Creosote Oil.
Fraction 4.—Anthracene Oil.
Remaining in the still — Pitch.

Each fraction is now redistilled to separate its constituents, which are many. The extent of the separation depends on the ultimate purpose of the products. Very rarely is an absolutely complete separation necessary. The main products obtained are:

From Fraction 1.—Benzene (or Benzole), Toluene, Xylene, Cumene.
From Fraction 2.—Phenol (Carbolic Acid), Naphthalene, a little Aniline, Cresols.
From Fraction 3.—Creosote.
From Fraction 4.—Anthracene.

Each of the substances enumerated now becomes a fresh raw material for manufacture. Industries of such immense dimensions have been built up to deal with them that an adequate description is not possible in a volume of this kind. A mere outline of the applications of some of them is all that will be attempted.

Benzene, often popularly confused with a liquid of similar sounding name but quite different, obtained from petroleum—Benzine—is a colourless inflammable liquid with characteristic but not unpleasant odour. It is used as a motor spirit either alone or mixed with petrol. As a solvent of oils, fats and resinous bodies it has many uses, but it is as a source of "Aniline" that its value is greatest. When it is treated with Nitric Acid (Aqua fortis) it is converted into "Nitrobenzene," an oily liquid with a strong smell of almonds. This has nothing to do with almond oil which it merely resembles in odour. It is known as Essence of Mirbane

and is used for scenting cheap scented soaps. The great value of the Nitrobenzene is that by a very simple process of reduction it can be made to yield Aniline. Benzene was known before it was found in coal tar, having been obtained from the natural resinous substance "Gum Benzoin," popularly known as "Gum Benjamin." It was not until 1845 that it was found in coal tar by Hofmann.

We now turn to the second product of the light oil fraction, Toluene, or Toluol. This too is a colourless liquid, somewhat similar to Benzene but less volatile. When it is nitrated—treated with Nitric Acid—it yields a highly explosive body, Tri-Nitro-Toluene, better known as T.N.T. and used as a high explosive for bursting charges in the Great War. From it also by chemical action can be obtained Oil of Almond, the true oil this time, not just an imitation of the natural oil but exactly the same as that obtained from the plant, the only difference between them is that in its production Nature has proceeded one way, the Chemist another.

The Xylene and Cumene are classed as solvent naphthas, and used as solvents of indiarubber for waterproofing, varnish making and such like purposes.

The second fraction contains two well known substances, Phenol and Naphthalene, the former better known as "Carbolic Acid"—although it is not really an acid—and the latter as "Moth Ball" on account of its general use for keeping moths from fur and woollen fabrics. The moths don't seem to like the smell of it, and I don't blame them overmuch. Phenol is a powerful germicide with a very wide application as an antiseptic and disinfectant.

When nitrated a yellow dye, one of the first coal tar dyes to be produced, called "Picric Acid" is obtained.

It has a very bitter taste and has certain uses as a bitter flavouring, is of value in the treatment of burns and is highly explosive. Gunnery experiments carried out with it at Lydd caused it to be called Lyddite. As a high explosive it was extensively used in the Great War. Care has to be taken that it does not come into contact with the metal of the shell because metallic picrates are apt to explode when not wanted.

The various Cresols are antiseptics and disinfectants.

The third fraction, Creosote, is mainly used for pickling timber. As is well known wood that is exposed to damp or buried in the ground is liable to decay. Telegraph poles, railway sleepers, hutments of all sorts, are made of wood that has been "creosoted," i.e., has had creosote forced into its pores. To be properly creosoted the wood should be thoroughly impregnated with the creosote and not merely have a surface covering. But the pores of the wood are filled with air and before the creosote can enter this must be removed. In Bréant and Burt's process the wood is immersed in a tank of creosote provided with an airtight cover and air pump attachment. Exhausting first air is extracted and creosote enters the pores; this is followed by a reversal of the pump, pressure is exerted and more creosote forced in.

Perhaps the most popularly known coal-tar product is Aniline on account of its association with the so-called "Aniline Dyes," better designated "Coal-Tar Dyes," because, although the first were obtained from Aniline, modern dye manufacture makes use of many other products from tar. Aniline was known long before it was obtained from tar having been obtained by the distillation of Indigo, the Spanish name of which is "Anil," hence the name given to the product. A

small quantity is found in the Carbolic Oil fraction, but the chief supply is from Benzene through Nitrobenzene. An important though chance discovery in 1856 marks the starting point of an industry of very great dimensions. The supply of Quinine which was obtained from a tropical plant having fallen off, a young man, W. H. Perkin, of Manchester, attempting to produce it artificially was led to try the effect of oxidation on Aniline (oxidation is the addition of oxygen to a substance). To his surprise he obtained a colouring matter with valuable qualities and high tinctorial power to which the name "Mauve" was given. The discovery created intense interest in the world of Applied Chemistry. Research on an extensive scale followed in which Germany took a very active part, resulting in a succession of discoveries of the utmost importance. Not only Aniline was used as a starting point but a host of other coal-tar products, many of which had hitherto had little value, were called upon. Colour after colour was obtained until every one previously derived from vegetable or animal sources was reproduced with a host of new shades in addition. As the chemical reactions became understood the old method of rule of thumb colour production gave way to scientific methods of precision of incalculable value to the dyer. Another side of the industry of equal importance has been the manufacture of the many chemicals needed for the reactions. Some of these are derived waste materials of other industries, some are entirely new. It will be readily seen that industries of vast dimensions were established in the years closely following Perkin's discovery.

The old saying that "One man's meat is another's poison" is exemplified in the colour industry. Two

colours obtained from vegetable sources provided occupation for large numbers of people and were an important source of revenue to the districts concerned. These were Indigo from a plant of that name cultivated in the East, and Turkey Red a particularly "fast" colour from the Madder plant cultivated on a large scale in Europe. The first to be affected was the Turkey Red. In 1868 this colour was obtained from Alizarin derived from Anthracene thus finding a use for a tar fraction of hitherto little value. To-day the cultivation of Madder for dye purposes has ceased. In 1880 artificial Indigo was obtained from Toluene. Although Indigo cultivation still goes on and some dyers still prefer it, its life is threatened by the artificial product.

To follow the development of the coal-tar colour industry is not the purpose of this book; enough has been said to shew its trend and the exercise of a little imagination on the part of the reader will give an idea of three-quarter of a century's advance.

But the story of coal-tar does not end here. A host of other substances too numerous to mention are obtained. Medicines of many kinds such as the Salicylates, Aspirin, Antipyrin, and many others are of coal-tar origin. Photography also is much indebted to it for developers such as Hydroquinone and Metol and the special colours used in Orthochromatic and Iso-chromatic plates to give colour values their true degrees of light and shade. In 1879 a substance of intense sweetness called "Saccharin" that can be used by people to whom sugar is prohibited was discovered. Scents and food flavours in great variety take the place of the natural bodies. These are not imitations but are identical with Nature's products although produced

in a different way. Almond essence has already been mentioned, another is Vanilla. Among scents may be mentioned Heliotrope, Rose, Lily of the Valley, Musk. The pathologist makes use of coal-tar colours for staining purposes to render disease bacteria more easily visible. Sanitary engineers take advantage of the great tinctorial powers of certain dyes to trace sewage leakage and water contamination.

Here is truly an amazing development involving much capital outlay and employing many people in connexion with a substance that not long ago was purely "waste material."

Low Temperature Tar.

The chemical reactions during the carbonisation of coal are of very complex character and the products obtained vary considerably under differing conditions of temperature and pressure. At low temperatures there is less gas and about twice the amount of tar whose composition is quite different from that we have been considering hitherto. In order to understand the difference, a little chemistry must be introduced into our account. Any compound containing Hydrogen and Carbon alone is called a "Hydrocarbon." There is an enormous number of such compounds, so many indeed that were it not that many of them are intimately related and able to be grouped together the chemist's task would be a difficult one. For convenience the chemist represents the elements in a sort of shorthand consisting of letters, sometimes one, never more than two. Hydrogen is H, Carbon is C, Oxygen is O, Chlorine is Cl. Each of these letters represents one atom of the element; if we wish to indicate more than one atom we attach a figure after the letter as H_2,

C_4, O_5, etc. When elements unite to form a compound we represent it by a "formula," made up of the letters (the "symbols") with their accompanying figures simply placed together such as H_2O (water), CO_2 (carbon dioxide), HCl (hydrochloric acid). These formulæ are merely empirical, giving no indication of the manner in which the compounds are built up. Other formulæ shewing this are known as "Constitutional" formulæ, but we will not trouble about those.

The simplest hydrocarbon consists of one atom of carbon combined with four atoms of hydrogen, represented therefore by CH_4 and called "Methane." It is well known as "Marsh Gas" and "Firedamp." It is the first member of a family of hydrocarbons with close chemical relationship. The following list gives a few members of the family with their names and formulæ:

Methane	CH_4
Ethane	C_2H_6
Propane	C_3H_8
Butane	C_4H_{10}
Pentane	C_5H_{12}
Hexane	C_6H_{14}
Heptane	C_7H_{16}

Succeeding members are given names similar to the last three in the list made up of a prefix indicating the number of Carbon atoms followed by "ane." It will be noticed that the number of Hydrogen atoms is in each case equal to 2 more than twice the number of Carbon atoms. They can all therefore be represented by a general formula C_NH_{2N+2}, where N is any number 1, 2, 3, &c. (All these hydrocarbons are very stable,

offering a strong resistance to any attempt to pull them asunder. This property is expressed by the two Latin words "PARUM AFFINIS." Taking the first syllable of the first word and the first two of the second the word "PARAFFIN" is obtained. All hydrocarbons having the composition of $C_NH_{2N}+_2$ are known as "Paraffins," the whole series being called the "Paraffin series."

Another series known as the "Olefin series," with the general formula C_NH_{2N} is also well known. A few of its members are:

Ethylene	C_2H_4
Propylene	C_3H_6
Butylene	C_4H_8
Pentylene	C_5H_{10}

etc.

One more series must be mentioned, this being the one with the general formula C_NH_{2N-6}, the first member of which is Benzene C_6H_6. A few members of this series are:

Benzene	C_6H_6
Toluene	C_7H_8
Xylene	C_8H_{10}
Cumene	C_9H_{12}

The series is sometimes called the "Aromatic" series and the paraffin series the "Aliphatic" series.

Natural petroleum is a mixture of a large number of hydrocarbons, probably thirty. In the oils of the West paraffins predominate, in those of the East olefins are most common. They are separated by distillation.

When high-temperature tar is distilled the substances

obtained are members of the Benzene series, but in the distillates of low-temperature tar there are none, instead there are paraffins and olefins. Here then is a means of producing the oils we need from our vast coal supplies instead of having to import it. Whether this can be done on a sufficiently paying scale remains to be seen. Much depends on a well-balanced demand for the by-products. Oil was once faced with similar difficulties but they have been overcome, and there seems no reason why those facing coal-oils may not in time also be surmounted. At any rate, a start has been made, and there is a determination to give it a fair trial.

It may be that some other method of obtaining oil from coal on a commercial scale will solve the problem, Hydrogenation for example, but that it will eventually be solved there is no doubt.

Two methods of using coal for fuel must be briefly mentioned; both have been extensively tried, and although opinions on their value differ they are both well-spoken of. The problem of the coal user is how to get the maximum of energy from it with the least loss. There is the old plan of stoking a furnace by hand labour and removing clinker also by hand. This has been much improved upon by mechanical appliances which are automatic in action. Coal is mechanically loaded from ship or truck on to a travelling "Conveyor," is automatically weighed on the way, introduced into the furnace, the ash and cinder removed and carried away. In all this it is never touched by hand.

Another plan is to pulverize the coal, reducing it to such fine powder that it can be blown by compressed air through small nozzles into the furnace, where it burns at once very much like a gas.

Still another method is to mix the powdered coal

with a fuel oil and spray the mixture into the furnace under pressure.

The battle goes on. Coal contains a certain definite amount of potential energy. The problem is to tap that supply with least waste. We have been scandalously wasteful in the past: we have lived in spendthrift fashion. The stress of modern conditions has made us pause and take stock of our position and there is every prospect that we shall profit from our experience.

CHAPTER VIII

THE RARE GASES OF THE ATMOSPHERE

THAT we are surrounded by an atmosphere seems obvious, that it is material and has weight is also common knowledge. It is strange that the philosophers of early times should have discovered so little about it. That it has weight was not clearly shewn till the middle of the 17th century, when Torricelli performed his famous experiment. Boyle had previously investigated its "springiness" and gave us the laws associated with his name. His contemporary, Mayow, had a glimmering idea of its complex nature, but we had to wait until after the middle of the 18th century before its true nature was disclosed by the labours of Scheele, Priestley and Cavendish. It was not until the true nature of combustion was discovered that the part taken in it by the air was clearly understood.

For about 150 years the chemistry of combustion was overshadowed by a great fallacy which has been described as the last of its kind to hinder scientific progress. Stahl, who was born in 1660, taught that combustible substances burnt because they contained a mysterious principle which he called "Phlogiston" and that in the burning it escaped, giving rise to the flame. Some substances such as carbon contained a good deal of phlogiston, that being the reason why heating a metallic oxide with carbon reduced it to the state of metal restoring to the metal the phlogiston that it lacked. As the use of the balance became more general it was pointed out by several experimenters that if the products of combustion are not allowed to escape there

is an increase of weight. It can be easily shewn that a candle plus the products of combustion weigh more after burning than before. Phlogistonists, faced with this awkward fact, were equal to the occasion, declaring that phlogiston was not like ordinary matter, instead of possessing weight it possessed lightness, therefore the more you had of it the less it weighed! The notion did not die until after the end of the century and it is rather remarkable that the two men who did most in administering its death wound, Priestley and Cavendish, remained convinced phlogistonists to the end of their days. Truly they could not see the wood for the trees.

The first direct evidence of the composite nature of the air was provided by two men working independently and unknown to each other, William Scheele in Sweden, and Joseph Priestley in England. In 1774, the latter announced that he had obtained from air a gas with an extraordinary power of supporting combustion. It was the very opposite of a combustible body, therefore it could not contain any phlogiston. He named it "Dephlogisticated Air." He observed that anything that would burn in air would do so much more readily in his new gas, also that many things usually regarded as incombustible would burn in it. Soon after Priestley's announcement there came the news that Scheele had also found the same gas and because of its power of supporting life had named it "Vital Air." A somewhat bitter controversy now arose on the question of priority of discovery, but there is now no doubt that although Priestley made the aanouncement first Scheele was first in the discovery. The name "Oxygen" was given to the gas some years later by the French chemist Lavoisier, who, hearing

of Priestley's experiments repeated them, obtaining the gas by heating lead in air until a scum formed on the surface, then heating the scum more strongly and collecting the gas given off by it. Lavoisier found that many substances when burnt in the gas produced acid. He therefore came to the conclusion, now known to be erroneous, that the gas was present in all acids and was responsible for their acid character. He therefore named it "Oxygen," the "Acid Producer": as such it is still known and the name, though incorrect, will remain.

Both Scheele and Priestley found that when the active constituent of the atmosphere was removed there was still a good deal left. It was Henry Cavendish who investigated this residue, eventually discovering the true composite character of the atmosphere as also he did a little later with water which had been regarded from time immemorial as primitive and simple. Cavendish found that the air-residue was the same as a gas obtainable from Nitre (Saltpetre), therefore he named it "Nitrogen," the Nitre producer. Other gases are present in air in varying amounts as impurities such as water, carbon dioxide, ammonia, various products of combustion and of organic decay.

When all impurities are removed air contains about 21% Oxygen and 79% Nitrogen; animal life needs the former, vegetable life the latter. As mentioned in the last chapter, although there is such a large supply of this essential plant-food it is not in an assimilable form. Certain plants such as beans are able with the aid of certain bacteria existing in soil to make use of atmospheric nitrogen but the power is denied to the generality of vegetation. It has been known for ages that a certain rotation of crops in farming is

necessary, but it is probably not well known that the inclusion of beans in the rotation introduces from the air nitrogen that other crops have removed.

That some elements can have different forms (allotropic forms) has already been mentioned. Oxygen can behave in this way, occurring as "Ozone." It is popularly believed that it is the presence of Ozone in the air that is responsible for the bracing and restorative properties of sea and mountain air. It is true that Ozone is a powerful germicide and antiseptic but it is very questionable if it exists near the ground in sufficient quantity to have much effect. The difference between Ozone and ordinary Oxygen is that its molecule contains 3 atoms instead of 2 and is represented O_3, whereas ordinary Oxygen is O_2.

It must be pointed out that the composition of the atmosphere given above is that near the surface of the earth, i.e., within a few miles of it. At much greater elevations the composition is believed to be very different. Evidence of this is so far only available from the spectroscope study of the Aurora, but several other considerations lead to the same conclusion. At a height of 60 or 80 miles there is probably very little Oxygen and Nitrogen but a good deal of Hydrogen and Helium. Owing to the lightness of the two latter natural diffusion would be responsible for their removal to high levels.

A natural question about the air is—"Are the principal constituents combined together or simply mixed?" A fundamental requirement of combination is constancy of composition. We can mix things in any proportions we like but we can only combine them in certain definite proportions over which we have no control. We can mix carbon and sulphur as

we wish and all we shall get will be a greenish powder in which a magnifying glass will disclose yellow particles of sulphur and black ones of carbon. If we combine them we must have 12 parts Carbon with 64 parts Sulphur and the resulting compound is a colourless evil-smelling liquid.

Suppose we apply the constancy test to the air. Samples of it have been taken from all sorts of localities, mountain tops, deep valleys, over land, over sea, in the Tropics, in the Arctic Circle, over desert, over swamp. In every case analysis has shown the general composition already stated. This suggests combination. But there are slight differences and this suggests mixture. This latter is confirmed in several ways:

(*a*) If air is dissolved in water and then extracted from it by boiling, its composition is Oxygen 35%, Nitrogen 65%. If it were a compound its composition would be the same afterwards as before.

(*b*). If Oxygen and Nitrogen are simply mixed together in the requisite proportions the mixture has all the properties of natural air.

When we consider the consumption of Oxygen by the respiration of all kinds of animal life, by combustion of every sort, furnaces, domestic fires, gas fires, cooking stoves, even cigarettes, we would expect the oxygen to shew a diminution over a long period of years, yet such is not the case. We must therefore conclude that there is some compensating influence at work, some means of renewal. It is generally considered that green vegetation is responsible for restoring the balance. It can easily be shewn that in the presence of sunlight and moisture vegetation, by means of the breathing pores on its leaves (the stomata) and its green life principle

(the chlorophyll) can break up the carbon dioxide present into carbon and oxygen, use the former to build up its tissues and return the oxygen to the air. Animal and vegetable life thus interact and keep up the balance of Nature.

Of the impurities present in air the most important are water and carbon dioxide. That the former is always present is easily proved by exposing some hygroscopic substance when its change of condition will provide evidence of the absorption of moisture. Everyone who wears glasses has the experience of the formation of a film of moisture on entering a warm room on a cold day. The amount of moisture that the air can hold without precipitation depends on the temperature, warm air can hold much more than cold air. The sudden cooling of moist warm air by contact with a cold surface or a cold air current is a cause of cloud, fog and rain. The average amount of moisture present is round about 1%. It can easily be removed by passing air through or over some desiccating substance such as quicklime, sulphuric acid or phosphorus pentoxide.

The presence of Carbon Dioxide (CO_2) is due to animal respiration, combustion of coal, wood, or hydrocarbons. It can be detected in many ways, the simplest being by the production of a white cloudiness in clear lime-water. Exposure of it in an open dish is quickly followed by the formation of a thin film on the surface. It can be removed by passing air over an absorbent of CO_2 such as caustic soda. The average amount of CO_2 present is a little under 0.04% (about 4 parts in 10,000).

There are two chief agencies at work which keep the various atmospheric constituents uniformly mixed in spite of the influences tending to disturb the pro-

portions. One of these is wind—the result of differences of pressure, the other is "Diffusion." This is a molecular motion of universal existence. When any two substances in the fluid state, i.e., whose particles are able to move freely among one another, have different densities and are either in free contact or are only separated by a porous barrier, each one passes into the other. The air therefore is extraordinarily uniform in composition the world over.

In what follows it must be understood that in the mention of experiments with air it is purified air that is used, air with all its known impurities carefully removed.

The first complete analysis of air was made by Cavendish in 1781, when he gave its composition as Oxygen about 21% and Nitrogen 79%. A little later, in 1785, he gave an account to the Royal Society of more precise experiments. He then stated, *but with great diffidence*, that there was an indication of a small amount of something else. He could not be quite sure of this. It might be due to imperfect purification of the air, or a slight leak in his apparatus or some other imperfection. He thought he had foreseen every possible source of error and had taken necessary precautions but in spite of all he could do there still remained this very small amount of something else.

For about 100 years the matter remained as Cavendish left it. Hosts of careful experimenters made analyses of air, some of them of world-wide reputation, but nobody detected Cavendish's "residue." We had to wait until the genius and patience of Lord Rayleigh and his fellow-workers brought to light this elusive residue and at the same time gave to science gases of an entirely new character.

In 1882, Rayleigh commenced a re-investigation of the density of Nitrogen. In determining the density of a gas the weight of a certain quantity of Hydrogen is obtained and the weight of the same quantity of the gas in question is compared with it, one being expressed in terms of the other. In principle the method is simple but in practice requires great delicacy in the apparatus and skill on the part of the operator. But it had been done over and over again by skilled workers who were in agreement up to a certain point and disagreed beyond that point. All agreed that as compared with Hydrogen = 1, the density of Nitrogen was 14 and a small fraction; there was agreement up to the second decimal place but disagreement at the third. Now it might be thought that here was surely accuracy sufficient. Why trouble about a few thousandths of a unit out of 14 units. Rayleigh felt sure there must be some reason for this and set to work to look for it.

When an element is very active like Oxygen or Chlorine it is very easy to get rid of it by allowing it to combine with something else. Nitrogen, however, is inactive, is disinclined to enter into direct combination with other elements and is therefore difficult to remove. On the other hand its compounds are often very active; one of them, Nitric Acid, is a powerful acid, another, Ammonia, is a well known alkali, whilst practically all high explosives are Nitro-compounds. Rayleigh in his work obtained the Nitrogen from two sources, (*a*) the atmosphere, (*b*) compounds of Nitrogen such as Ammonia and Nitric Acid. After ten years' work, in 1893, he announced to the Royal Society he had found agreement in that third decimal place but had come across another difficulty. It was this. His results from

the atmospheric Nitrogen were in agreement with one another and so were those of the Chemical Nitrogen but he could not get agreement between the Chemical and atmospheric Nitrogen, the latter was *always heavier than the former by* 1 *part in* 230. He also had confirmed Cavendish's result by observing that when the atmospheric N was mixed with pure O and a torrent of electric sparks passed through the mixture the N and O combined together but at the end there was left a very small residue incapable of further removal. It was suggested that just as the passage of an electric discharge through Oxygen changed some of it into Ozone which is heavier, so the effect of the electric bombardment of the Nitrogen might have converted some of it into a heavier allotropic form. Not satisfied with suggestions made, a letter was inserted in a number of *Nature*, a weekly scientific publication, stating the facts and asking for suggestions; no satisfactory reply however was forthcoming.

Sir Wm. Ramsay now joined Rayleigh, attacking the problem in another manner. It has been mentioned that Nitrogen is very inactive, but it does combine with Magnesium when strongly heated. Ramsay therefore passed N over hot Magnesium for long periods and was able to announce that atmospheric N so treated became heavier. Finally, when no further concentration could be detected the residue was strongly sparked. At the Oxford meeting of the British Association the final result was announced that the long-sought gas was discovered. It was clearly proved to be a new element with a definite spectrum, its density was 20 as compared with Nitrogen 14 and it was present in the atmosphere in amount about 1%. And this was the cause of the greater density of atmospheric Nitrogen.

It was the first of an entirely new class of element, absolutely inert, incapable of combination with anything else. Because of this peculiarity it was named "ARGON" the "Idle One," from the Greek word "Argos," meaning "lazy." The discovery of Argon stands out as an example of patient, dogged determination coupled with scientific genius. There have been more spectacular discoveries but none of greater scientific interest.

It was known that certain minerals containing Uranium, of which Cleveite was one, when treated with an acid yielded Nitrogen. It was suggested that this was not the result of a chemical decomposition but that perhaps the N was merely "occluded" in the pores of the mineral and liberated in the process. On this supposition the N was possibly imprisoned millions of years ago when the Cleveite, an igneous rock, was in a molten condition. If so, an examination of the N would give some information of the composition of the atmosphere at that far-off time. Ramsay with difficulty obtained a small specimen of Cleveite, extracted the Nitrogen and treated it as had been done in the Argon experiments. Sure enough a small residue was obtained in this case also. But when its spectrum was examined —this being the only means of identification—it was found *not to be Argon*. Deciding that it was another new element, Ramsay called it "Krypton" (the hidden one). In order to get confirmation of his deduction he sent a sample to Crookes for more exact spectroscopic examination. In response Crookes sent a telegram with three momentous words, "Krypton is Helium."

Up to this time Helium had been regarded as a celestial element only. During an eclipse of the sun in 1868, when the chromosphere was examined for the first

time with a spectroscope, certain lines were observed that were unknown and were attributed to an element in the sun not existing elsewhere, therefore the name "Helium" was given to it, from the Greek "Helios"—the sun. Here was Helium found on earth for the first time. We now know since the discovery of Radium that Helium is always produced during α-ray emission in radioactive change, that being the reason for its presence in the Cleveite.

Two gases of an entirely new class having been found there were reasons based on the "Periodic Law" for suspecting the existence of one or two others. A search for these was commenced in 1896 at University College, London, in which Travers and Collie co-operated with Ramsay. Up to this time Argon and Helium had only been obtained in almost microscopic quantities. For a systematic investigation much larger amounts would be required. Fortunately another discovery about this time gave the means of large supplies of Argon. This was the discovery by Hampson and Dewar of a ready method of liquefying air.

A little digression must be made here. The problem of liquefaction of gases had received much attention. Some gases such as Sulphur Dioxide and Carbon Dioxide can be liquefied easily at moderate temperatures by compression. Others must be very much reduced in temperature before any degree of compression will liquefy them. A few like Nitrogen resisted all attempts and were regarded as permanently gaseous. Time, however, has shewn that there is no such thing as a permanent gas; given sufficiently low initial temperature and high pressure all gases may be liquefied and even solidified. Hampson and Dewar's method is known as the "Regenerative" or "Self-cooling"

method. By means of it liquid air has now become an article of commerce and can be bought by the gallon.

To resume: Liquid air is a mixture of its liquefied components, i.e., liquid N, liquid O, liquid Argon and liquid anything else it may contain. As we have already seen, a mixture of liquids with different boiling points can be separated by distillation, each constituent coming away at its own boiling point. As the boiling point of Nitrogen is 195°C. below zero (−195°C.), that of Oxygen −182°C. and that of Argon −186°C., no heat need be applied. At ordinary temperatures the Nitrogen evaporates first, followed by the Oxygen. By careful repeated self-distillations therefore, large quantities of Argon were obtained and examined for any possible other members of the newly-discovered class of inert elements. After 5 years' work the complete story of the atmosphere was unfolded. Three new inert gases were added to those already known, Neon with an atomic weight of about 20 (H=1), Krypton—the true Krypton this time—with atomic weight 83 and Xenon with atomic weight 130. The amount of all together is very small, being only about 1%. According to Ramsay the quantities present are:—

Argon 0.9 parts in 100	parts of air
Neon 1 part in 100,000	„
Helium 4 parts in 1 million	„
Krypton 1 part in 1 million	„
Xenon 1 part in 20 million	„

The final stages of the separation are by no means easy. In the Neon fraction Helium is always present and is removed by cooling with liquid Hydrogen

(-253°C.) when on subsequent evaporation the Helium passes away leaving Neon behind. When the properties of Radon were examined it was found to belong also to this class.

The inert gases in use.

Until 1917 Helium was only obtainable in small quantities. In that year it was found to exist in much larger amount in the natural gas of petroleum districts especially in U.S.A. and Canada, from which it could be extracted by liquefaction and fractional evaporation. In this way large supplies are now available. Since it is the next lightest gas to Hydrogen with a lifting power very little less, its inertness and therefore non-inflammability makes it especially valuable for the inflation of airships. It is used for this purpose in the latest types of American airship. Unfortunately it cannot be manufactured, so that natural supplies have to be relied upon.

Everyone is familiar with the brilliant coloured electric signs in our large towns. These are produced by electric discharge through glass tubes containing rarified Neon. Unlike most gases the luminosity can be produced by only moderate voltage. Neon alone gives a brilliant red colour, a small quantity of Mercury in the tube changes the colour to Blue, other colours are produced by colouring the glass of the tube. The Neon light has good fog penetrating powers and is therefore in requisition at aerodromes for night-flying.

Argon is valuable in the production of gas-filled electric lamps. In the ordinary exhausted incandescent lamp the tungsten filament cannot be heated to the temperature of its greatest brilliance because in the absence of pressure it would volatilize. By

filling the bulb with Argon which, on account of its inertness has no action on the filament, the temperature can be raised to the point of greatest incandescence without risk of disintegration.

Up to the present no use has been found for Krypton and Xenon.

Radon is valuable as a source of vigorous high-velocity α-particles in the treatment of disease.

Cavendish little thought what the result would be of his diffident reference to a small unexplainable residue in his analysis of air.

Because of their exclusiveness, their freedom from attack by other elements, the gases here described are sometimes spoken of as the "Noble Gases."

CHAPTER IX

ATOMS AND THEIR RELATIONSHIPS

THE late years of the 18th century saw great changes in scientific thought. Oxygen was discovered by Scheele and Priestley, the composite character of the air and of water were investigated by Cavendish, the use of the balance and the importance of weight relationships in chemical reactions were more fully understood, the true nature of combustion was pointed out by Lavoisier and the death-blow administered to the more than century-old fallacy of Phlogiston. The term "Element" came to have a more precise meaning as being a substance that could not be reduced to a simpler form, the number of such at the close of the century being estimated at about thirty.

The discovery of the electric current at the beginning of the 19th century, with its great power of breaking up previously undecomposable substances was responsible for a great and rapid increase in the number of elementary bodies. Between 1804 and 1827 about 16 new elements were discovered, many of them from quite common well-known materials. Sodium was obtained from Soda, Potassium from Potash, Magnesium from Magnesia, Boron from Borax, Bromine and Iodine from seaweed, Aluminium from Clay, whilst among rarer elements Osmium, Iridium, Rhodium, Palladium were isolated.

The year 1808 saw Dalton's Atomic Theory launched. It was not new; in the 4th century B.C. the Greek philosopher Democritus wrote "In infinite Space is an infinite number of Atoms. These atoms are eternal

and invisible, absolutely small, so small that their size cannot be diminished. The only things that exist in reality are the Atoms and the Void. The Soul is composed of smooth round Atoms specially mobile and similar to Fire Atoms. Life is maintained by the inhalation of Atoms to replace those lost by exhalation.")
Dalton, in considering the way in which the elements combined to form compounds, the definiteness of the proportions and the invariable constancy of composition of the resulting compounds, was led to the conclusion that combination did not take place between the masses of the elements as a whole but between separate very small portions which together made up the whole. These separate individual parts were eventually called "ATOMS." Although the idea had the active support of Thomson, Avogadro, Wollaston, Berzelius, among others, it did not receive immediate general acceptance. Sceptics were however eventually compelled, by the overwhelming evidence in its favour which accumulated as the result of experiment, to admit its validity. It became established as one of the pillars of chemical and physical science, a position which it has ever since maintained in spite of several severe shocks. An atom is so tiny that the imagination has to be actively exercised to get a faint idea of it. Nobody has seen one nor can hope to do so, yet Modern Science can shew the effect of a single atom in flight, the X-ray spectroscope can show their arrangement in a molecule, the Mass-spectrograph measure the weight and we know a good deal but by no means all about its internal anatomy. Dalton and his contemporaries and scientists generally for many years afterwards had no notion that it had an inside, to them it was indivisible, unchangeable. They were concerned with its external characteristics,

its relations with other atoms, its groupings into molecules and its readiness or disinclination to unite with other atoms. Instead of the vague, ill-defined atom of Democritus and Aristotle Dalton gave us the clear-cut idea of an atom as the smallest portion of an element that can enter or leave a compound and it remains such to this day.

The importance of weight and of weight relationships in chemical reactions had been realized since Lavoisier's explanation of combustion. Much attention was therefore given to the weight relationships of the atoms of different elements. The determination of the weight of a single atom was obviously out of the question, but by taking that of the lightest atom as unity it was possible to obtain the " relative weights " of others. Wonderful accuracy was achieved in this work by such men as Berzelius and Stas, work requiring high qualities of patience and skill. Hydrogen being the lightest element was taken as the standard, the weight of its atom being called " 1 " (for convenience Oxygen = 16 is now generally taken as standard), the atoms of other elements having numbers which mark their weights relative to the standard. Thus C = 12 because the atom of carbon is 12 times the weight of that of Hydrogen, N = 14, O = 16, etc.

As the number of newly discovered elements increased the question arose whether there were in reality all these different kinds of matter. One reason for the question was that " allotropy " had been discovered, the ability of an element to have more forms than one, the forms differing as much as one element from another. Thus the three allotropic forms of carbon, Lampblack, Graphite and Diamond, were as unlike each other as if they were different elements. Instead

of there being so many elements might there be a single primitive element, the others being merely allotropic modifications of it? The notion had existed from very ancient days. Various things in turn had been suggested as the primitive stuff, air, earth, fire, and in the 6th century B.C. Thales of Miletus considered it to be water. The fact that sometimes water left an earthy residue when evaporated was cited as evidence in support until Lavoisier shewed conclusively that it was nothing of the kind, but was due to the hard water holding mineral matter in solution. Induced by the fact that many of the atomic weights of the elements seemed to be simple multiples of that of Hydrogen, i.e., were whole numbers—within the limits of possible experimental error—Prout in 1815 suggested that the primitive matter was Hydrogen and that all the other elements were merely allotropic forms of it produced by the grouping together of different numbers of atoms of it. The theory received a certain amount of support which dwindled with the discovery that there were numerous elements with fractional atomic weights which ought not to be since an atom could not be divided. It was further suggested that in place of Hydrogen some unknown lighter substance, to which the name "Protyle" was given might be the required primitive matter. Prout's hypothesis gradually lost favour and was added to the many abandoned theories of past days.

Although Prout's theory was dead there was still a lingering feeling that Nature is inclined to simplicity and that the existence of a large number of unrelated heterogeneous elements was not to be expected. Reasons in support were not wanting, strong family likenesses were observable among some of the elements, many

instances also occurred of elements always being so closely associated in nature that their separation was difficult. It seemed unlikely that mere chance could account for these relationships and associations. Consequently the scientific mind was on the alert for anything that could throw a light on the subject or provide a clue that might be followed with advantage.

About 1825 Dobereiner and Dumas divided certain groupings of elements with related properties into sets of 3, known as "Dobereiner's Triads." Typical examples are given below omitting fractions in atomic weights:

Chlorine	—Cl	atomic weight	35
Bromine	—Br	,, ,,	80
Iodine	—I	,, ,,	127

Adding together 35 and 127 and dividing by 2 we get 81. Thus numerically Br is intermediate between Cl and I. In physical state a similar connexion is seen for Cl is a gas, Br a liquid and I a solid. In chemical activity too Br is the mean between Cl and I. In other respects also a similar relationship can be observed. Another triad group is Lithium 7, Sodium 23, Potassium 39; another is Calcium 40, Strontium 87, Barium 137. Others can be mentioned, but enough has been said to indicate the kind of relationship observed. Although a definite relationship was indicated in the triad groups there was nothing to connect group with group so interest in them declined.

In 1866 Newlands noticed that if he arranged the elements in the order of their atomic weights every successive eighth element was a repetition of the first in many respects. Because in music every eighth note is a repetition of the first in a different *octave*, Newlands

called this relationship among the elements the "Law of Octaves." The following will give an idea of Newlands' classification :—

Lithium	Li	7	Sodium	Na	23	Potassium	K	39
Beryllium	Be	9	Magnesium	Mg	24	Calcium	Ca	40
Boron	B	11	Aluminium	Al	27	(Titanium	Ti	48)
Carbon	C	12	Silicon	Si	28			
Nitrogen	N	14	Phosphorus	P	31			
Oxygen	O	16	Sulphur	S	32			
Fluorine	F	19	Chlorine	Cl	35·5			

We have ended the list at Calcium but Newlands continued it to the last of the known elements. The "octaves" of Lithium will be seen to be Sodium and Potassium which are undoubtedly closely related both chemically and physically to it. Similarly the "octaves" of Beryllium (Calcium and Magnesium) are related. But when Newlands read his paper before the Chemical Society of London in 1866 members pointed out that although there were many agreements there were far too many disagreements. The third place for example shewed this: the first "octave" of Boron was Aluminium which was quite right, but the second was Titanium which really ought to be in the next place as related to Carbon and Silicon. Similar discrepancies were shewn to occur in other parts of the list. The scheme met with no encouragement, one of the members even scoffingly asked if he had ever thought of arranging the elements in the order of their initial letters?

Nevertheless Newlands was on the right track. He failed through not foreseeing the discovery of new elements which would need a place in any classification.

The necessity for such provision was realized by the Russian chemist Mendeléeff, who was working independently along similar lines. His profound chemical knowledge enabled him to place the elements into their proper family groups which did not fall there naturally. In order to do this he had to leave a number of gaps in the list to be filled later by new elements. He observed as Newlands had done that with steadily increasing atomic weight the properties recurred periodically. He therefore enunciated the relationship as "The chemical and physical properties of the elements are Periodic Functions of their Atomic Weights." (A periodic function is a relationship that repeats itself at regular intervals.) This has since been known as "Mendeléeff's Periodic Law."

When it was brought to the notice of the Scientific Societies it too was rejected. It was pointed out that by leaving gaps when he found the elements would not fit he was "cooking his accounts" and that by so doing it was possible to make Laws out of anything. Mendeléeff however was not deterred by this rebuff, he had the courage of his convictions and ventured on prophecy. An illustration will help in this. Take the first members of the octaves in Newlands' list: Lithium Li 7, Sodium Na 23, Potassium K 39. Suppose Li and K to be known but Na to be unknown. Sodium is the mean between the other two: its atomic weight is $\frac{7+39}{2} = 23$, its other properties can be similarly determined. Mendeléeff pointing to one of the gaps in his list said in effect: "I will tell you all about the element that will fill that space, and I will stand or fall by the result." That was in 1869. In 1875, six years later, a French chemist Boisbaudran

discovered an element which he named "Gallium" in honour of his native country, which fitted the gap like a dovetail. Its weight and other properties were in almost absolute agreement with the prediction.

The scientific world was even now unconvinced. A further discovery by Nilson in 1879 of an element which he called "Scandium" which dovetailed into another of the spaces caused opposition to weaken. By the discovery of a third element in 1885 by Winkler and named by him "Germanium" the Periodic Law became recognised as a valuable classification. It was the first general means of linking one element with another indicating relationships which led to the discovery of still more new elements to fill the vacant places and altogether has proved to be of immense service. It was not perfect but its defects were far outweighed by its advantages. It was an empirical arrangement with no underlying principle: there was no apparent reason for it. It was based on the *weights* of the atoms, that is to say on something which is not inherent. Although weight is an important property of matter it is not part of the matter itself, it is something additional and varies with varying circumstances. A pound weight at the Poles is not a pound at the Equator and would be only about 2½ ounces on the Moon. But the same matter would be there. Moreover there were certain elements that could not be satisfactorily provided for by it. There was no obvious place for the Inert Gases nor for certain important elements occurring in groups of 3, such as Iron, Cobalt and Nickel, or Osmium, Iridium and Platinum.

For about a hundred years from the time of Dalton's Atomic Theory it had been assumed that all the atoms

of any element were alike and had the same weight; no means was known of putting the matter to the test. One of the reasons for the decline of Prout's Hypothesis was that the element Chlorine had an atomic weight of 35·47 and nothing that could be done by purification or experimental precision could obtain any change in that figure. By means of an apparatus devised by J. J. Thomson, called a "Mass Spectograph," Aston of Cambridge in 1919 was able to shew that Chlorine atoms are not all alike, some having a weight of 35, whilst others weigh 37. These differently weighted atoms of an element are called "Isotopes." Their chemical properties are precisely the same, they behave in the same way, their only difference is their weight. The reason for the number 35·47 is that any sample of Chlorine in its natural state consists of a mixture in definite quantities of the two isotopes 35 and 37 giving an *average* atomic weight of 35·47. Further investigation has shewn that few, if any, of the elements are free from isotopes, some having as many as 10. Whole-number atomic weights are therefore very general and Prout may not have been so far wrong after all. The radioactive elements have been of especial value in providing verifiable evidence in support of mass-spectrograph results. The discovery of isotopes is one of outstanding importance and has helped to solve some of the troublesome features of the Periodic Law such as the anomalous positions of Tellurium and Iodine. The separation of the isotopes is a matter of extreme difficulty owing to their chemical nature being identical. If all the isotopes of every element could be separated it might be possible to remodel the Periodic Law so that it would conform more closely to modern knowledge.

X-ray Spectra and Atomic Numbers.

We have seen that a beam of light consisting of different wave-lengths can be separated by a transparent prism or by a grating consisting of fine lines ruled very close together on glass. But any such arrangement is useless for X-rays because their wave-lengths are so much shorter than those of light. It was found quite impossible to rule lines sufficiently close together for the purpose. The difficulty has however been overcome through the ingenuity of Von Laue in Germany and Bragg in England. In a crystal the atoms are arranged in an orderly manner and in certain crystals the rows of atoms can take the place of the lines on a grating. By using such a crystal and passing a beam of X-rays through it, it has been found that they too, like light, are of different wave-lengths and can be separated and sorted into a spectrum. As the wave-lengths are much too short to affect the eye they must be recorded on a photographic plate. The X-ray spectroscope has now become an instrument of extraordinary precision providing an inside knowledge of the structure of crystals and leading to discoveries of far-reaching importance.

It has been found that the X-rays emitted from an X-ray bulb consist of two parts, one being a general emission, the other an emission of definite wave-length depending on the material of the anticathode. In 1913, Moseley of Oxford, a brilliant experimenter, whose death at the Dardanelles in the Great War was a great loss to Science, using anticathodes of different materials made a systematic study of these characteristic X-rays. In the spectrum of light there are many lines but they sub-divide into definite series

of lines known as the "Balmer series," the "Lyman series," etc., numerically related to each other in a well-known way. The X-ray spectra consist of very few lines also forming groups known as the "K-group," "L-group," "M-group," "N-group." The "K-group" consists in each case of a small cluster of lines fairly close together. When Moseley obtained the X-ray spectra of a number of elements and arranged them under one another in the order of the Periodic Law it was seen that the groups of lines also arranged themselves in an orderly manner so that they looked like the steps in a staircase. This regularity was so striking that it could not be a mere chance arrangement. It will be remembered that in the Periodic Law there is a periodicity in the properties of the elements as they advance in weight, that there are certain elements for which there seems to be no place and that there are certain others whose positions need reversing. If the elements are arranged according to their X-ray spectra, following the regular step by step order of the groups of lines they follow in the main the order of Mendeléeff's list, but *there is no Periodicity, there are no anomalies and there is a place for every known element. When we come to the place of a missing element there is a double gap between the steps.* Since the X-rays are a property of the inside of an atom an X-ray spectrum should tell us something that is fundamental and not something fortuitous such as weight on which the Periodic Law is based. According to the Moseley plan then, the elements are arranged in order with Hydrogen number 1, Helium number 2, up to Uranium number 92. The list is complete with two gaps at numbers 85 and 87, the claimants for inclusion in these places

not being sufficiently verified. Accordingly the total number of the elements should be 92. Radioactivity suggests that there may have been others beyond Uranium which owing to radioactive disintegration have disappeared in past geological time leaving us their descendants the present radioactive elements. Whether they still exist in deeper unplumbed depths of the earth's crust or in other planets we have no present means of knowing. It has recently (1934) been claimed by an Italian scientist that one of them—No. 93—has been artificially produced by the high-velocity bombardment of Uranium.

"Atomic Numbers" have therefore taken the place of atomic weights. There is general agreement between the elements so arranged and the Periodic Law except that the Periodic Law anomalies are non-existent. Each arrangement has its use but where there is disagreement the Atomic Number has the preference.

With the knowledge gained by the study of radioactivity and the high-velocity particles ejected in the process it is only natural that attempts should be made to discover exactly how and why the changes occur, how the atom is constituted. Many views have been put forward, but the one known as the "Rutherford-Bohr Atom" due to Lord Rutherford of Cambridge and Niels Bohr of Copenhagen has received the most general acceptance. The evidence in support cannot be given here but it has been provided by a host of experimenters in many parts of the world. Like taking a watch to pieces we will take all the things that have been obtained from atoms and then try to see how Rutherford and Bohr consider they are put together to constitute atoms as we find them :—

(*a*) *The Electron :* is the smallest in weight being about $\frac{1}{2,000}$ the weight of a Hydrogen atom, is only known when travelling at high speed, sometimes with nearly the velocity of light. It constitutes the components of the Cathode Stream of Crookes and the β-ray of Radioactivity. It always carries a *negative electric charge* of definite amount and is precisely the same from whatever source it is obtained. Because of its electric charge and its motion it can be controlled both electrically and magnetically. Both its weight and its velocity can be estimated with accuracy.

(*b*) *The Proton* : has the weight of an atom of Hydrogen and always carries a *positive electric charge* of definite amount, the same in amount as that of an Electron but of opposite kind. It is precisely the same whatever its source and because of its electric charge can be controlled in motion both electrically and magnetically. Both its weight and its velocity can be estimated accurately.

(*c*) *The Neutron* : was first found at Cambridge in 1932, by Chadwick, during the bombardment of Beryllium by rays from Polonium. It has the weight of an atom of Hydrogen but *has no electric charge* and therefore cannot be controlled electrically or magnetically. Whether it is an individual entity or a very intimate association of a proton and an electron has not yet been determined.

(*d*) *The Positron* : was discovered at Cambridge in 1933 by Blackett and Occhialini. It is the same as an Electron but with a *positive electric charge* instead of a negative.

(*e*) *The Neutrino*: with the same mass as an electron but no electric charge has certain claims for existence.

(*f*) *The α-Ray*: is expelled with high velocity from the atoms of radioactive elements. It is an atom of Helium with two positive electric charges, i.e., it is "ionised," and eventually becomes an atom of ordinary Helium by losing its electric charges.

For the benefit of the non-technical reader we may picture a positive charge as the *possession of a shilling* and a negative charge as *owing a shilling*. The discharging of the debt by the union of the plus shilling and minus shilling brings us to solvency with an empty pocket. Similarly the union of a plus charge and a minus charge gives us electric neutrality.

The Rutherford-Bohr atom is pictured as a kind of Solar System in which Protons, Electrons and the rest take the places of the Sun, Planets and Satellites. At the centre of each atom is the Nucleus whilst circling round it are Electrons. Just as the Sun holds the Planets on their orbits, preventing them from flying away into Space, so does the Nucleus hold the Electrons in their orbits, the attractive laws in both cases being similar. All the members of the Solar System are rotating on their axes as well as revolving about their primaries; there is strong reason for believing that the several units of an atom are doing the same.

It must be remembered that the picture here given is by way of illustration merely and must not be taken too literally. There are many differences; for instance, the Major Planets move in practically one

plane but the Electrons do not. Again, the planets do not change their orbits whereas the electrons can be forced out of one orbit and made to revolve in another one, or can jump back again of their own accord into the orbit they have left or even an intermediate one. The picture however will serve in the main if we bear in mind that we must not expect strict analogy.

In the case of every atom the "Mass" (weight) is concentrated in the Nucleus, the electrons by comparison are so light that their mass (weight) is negligible. The circling electrons on the other hand confer on the atom its other Chemical and Physical characters and its Spectrum.

The simplest atom and the lightest is that of Hydrogen; it consists of One Proton at the centre and One Electron circling round it, something like the Earth-Moon System. But relative to their sizes the Proton and its attendant Electron are much more widely separated than are Earth and Moon. *Therefore the atom is very empty.* This is true of every atom however heavy it may be. The Solar System is very empty too, so much so that if a projectile the size of the Moon could be fired into it, from a point outside it, would probably hit nothing. Lord Rutherford calculates that if the same thing were attempted with an atom using a projectile of relative size the chances against scoring a hit would be about a million to one against.

The next simplest atom is that of Helium with a Nucleus weighing four and two planetary Electrons. It is something like Mars with its two moons only Mars is too small for the analogy to hold good. We might mention here that Oxygen with eight

electrons is something like Jupiter with his eight or nine moons. The Nucleus of the Helium atom consists of 4 Protons, each of weight 1, and positively electrified. The atom as a whole is electrically neutral. Two of the four "+" charges are balanced by the two "–" charges of the two planetary electrons, the remaining two are balanced by two other electrons which are either within the Nucleus or so close to it as to form an essential part of it. Planetary electrons being much further from the Nucleus are more loosely held by it and can be driven away altogether in various ways such as electric repulsion or intense heat, leaving the atom with less than its normal electron quota. Such an atom is "ionised." A case in point is that of the "α-particle" of radioactivity which is a Helium atom without its two planetary electrons and is therefore ionised with a double + charge. As there are always plenty of free unattached electrons wandering about requiring a home the α-particle quickly annexes two and becomes a normal Helium atom. The Helium nucleus appears to be unique and extremely stable. In more complex nuclei containing many Protons there seems to be a tendency for them to group together into sets of Helium nuclei. In radioactivity for instance the disintegrating atom does not eject separate protons but groups of 4 (α-particles) which persist as separate entities without any further break-up.

The next element in order is Lithium with Atomic Number 3 and Atomic Weight 7. Its atom has a nucleus of 7 Protons, four of them as an α-particle group (4 protons with 2 intimate electrons), 3 others with 2 associated electrons and 3 planetary electrons further afield.

And so the list of elements continues, each succeeding one having 1 more planetary electron helping to confer upon it its ordinary chemical and spectral characters, its Nucleus gradually becoming more congested with the accumulation of Protons and their associated—or intimate or satellite—Electrons.

A brief summary may help us to understand the situation so far:

1°. According to Moseley's Atomic Number Law there are 92 Elements successively numbered 1 to 92. There may have been others beyond No. 92 but there is no trace of them and they were probably unstable and have broken down by radioactive disintegration in past ages leaving their long-life descendant Uranium as their representative.

2°. All the Elements are built up of the same materials—Protons and Electrons—differing only in the numbers of each. We are therefore in a sense back again to the ideas of Prout and Aristotle, their "Materia Prima" having become protons and electrons.

3°. The Chemical and Spectral characters of the elements are determined by the number of planetary Electrons, or as some prefer to express it by the amount of the positive electric charge on the Nucleus—the "Nuclear Charge." This is the same quantity because whatever the nuclear charge may be, in the neutral atom it is neutralized by the negative electric charges of the planetary electrons.

4°. Where an element has Isotopes its atomic number is unchanged, its planetary electrons are all the same, the only change is in the constitution of the nucleus. It is probably here that the "Neutrons" are concerned.

5°. An atom is very "empty," practically all its mass (weight) is concentrated in the nucleus which only occupies a small space within the atom; relatively the planetary electrons are far away.

6°. The planetary electrons can be forced away by heat, X-rays, radioactive bombardment or other causes, leaving the atom with its nuclear charge unbalanced. It is then said to be "ionised" and has not its usual properties because the planetary electrons are not there to confer upon it its characteristic qualities.

A list is given here of a few of the lighter elements with their atomic numbers and weights, fractions being omitted:—

Element	Atomic Number	Nuclear Charge	Atomic Weight
Hydrogen	1	+1	1
Helium	2	+2	4
Lithium	3	+3	7
Beryllium	4	+4	9
Boron	5	+5	11
Carbon	6	+6	12
Nitrogen	7	+7	14
Oxygen	8	+8	16
Fluorine	9	+9	19
Neon	10	+10	20
Sodium	11	+11	23
Magnesium	12	+12	24
Aluminium	13	+13	27
Silicon	14	+14	28
Phosphorus	15	+15	31
Sulphur	16	+16	32
Chlorine	17	+17	35
Argon	18	+18	36 & 39

The number for the nuclear charge is also that of the

planetary electrons each of which has a negative electric charge. It will be noticed that the Atomic Weight is roughly twice the Atomic Number. This relationship holds good generally for the lighter elements but for the heavier elements atomic weights are more than twice the atomic numbers; thus Silver with atomic number 47 has atomic weight 108, the corresponding figures for Lead being 82 and 207.

Transmutation.

The possibility of transmutation of one element into another has had a fascination for philosophers from very early times, especially that of changing a base metal such as lead into gold. Claims of success have been made from time to time but never substantiated. Many alchemists in the past worked at the problem and many owing to their failure came to an untimely —frequently painful—end at the hands of their disappointed patrons. Transmutation was the Alchemist's dream, *to-day it is an established scientific fact.*

Radioactivity gave us the first example of it. Uranium, for instance, by several stages of change, gives rise to Radium, which in its turn becomes Radon and eventually Lead, with Helium also as a product of several of the changes, all being true elements in the strictest sense of the word. But radioactivity is a natural process, we cannot control it either by acceleration or retardation. It is not transmutation as popularly understood although it is a change from a base substance, Uranium, to a very precious one, Radium.

If transmutation is to be achieved it is the Nucleus of the atom that must be altered. In the case of a

heavy element it is very stable and strongly guarded against attack by its electric charge. Consequently the attempt was made with the light elements whose electrical defence was not so great, and the first success was secured by Rutherford of Cambridge in 1919.

Let us try to picture the scheme of attack. First of all what do we mean when we say that an atom occupies a certain space? We have said that it is very empty, mainly nothing, a nucleus surrounded by circling electrons relatively far away with nothing in between. When we say that a military force occupies a territory we do not mean that the territory is filled with troops standing shoulder to shoulder, but that its boundaries are patrolled by troops sufficiently well armed to prevent a hostile force from penetrating them. Somewhat similarly the patrolling electrons of an atom armed with electric charges prevent a hostile atom from penetrating or even approaching too closely. If therefore the nucleus is to be successfully attacked it must be by something powerful enough to overcome or brush aside the defences. What artillery have we that we can use in the attempt to make a breach in the fortifications of the atom we are about to attack? For projectiles there are Electrons, Protons, Neutrons and α-particles. As regards propellents Electrons and α-particles have the explosive energy of radioactivity which is greater than anything we can provide. Protons and Neutrons must be supplied with the necessary propelling energy. In the case of Protons this can be done electrically, but the Neutron so far has no available means of propulsion. This is a great pity because it is by far the best projectile for the purpose. Being electrically neutral

the powerful electric charge of the nucleus of the attacked atom is powerless against it. Thus our most efficient piece of artillery is useless because we have no powder for it. The projectile with the greatest speed is the Electron but notwithstanding this its momentum is small on account of its small size. To attack a heavy nucleus with electrons would be rather like bombarding a battleship with pea-shooters. We are therefore left with α-particles and Protons.

The first successful attack was made in 1919 by Rutherford of Cambridge. The atom attacked was that of Nitrogen, the projectiles being high-velocity α-particles from Radium C. Let us be quite clear about what is being done. It is not a case of a target being set up and a shot directed at it. A quantity of Nitrogen contains myriads of atoms; a stream of α-particles is fired into it on the "off-chance" that some at any rate will score a hit. The result is that Hydrogen and Oxygen are found. Since the first success the experiment has been so frequently repeated that all room for doubt has gone. What has happened appears to be that an α-particle has hit a Nitrogen nucleus, been captured by it and a Proton (Hydrogen nucleus) has been expelled, or numerically:

Nitrogen (14) + Helium (4) = Hydrogen (1) + Oxygen (17) (Isotope).

The same thing has been done with many other elements with similar results, an element higher up the scale, i.e., of higher Atomic Number, being produced along with Hydrogen.

In 1932 Walton and Cockcroft under the direction of Rutherford at Cambridge used Protons in an attack on

Lithium. A bulb of Hydrogen under low pressure provided the Protons which were given a high velocity by an electric pressure of about 500,000 volts. Directed on to a target containing Lithium, Helium atoms were obtained. This was the first occasion on which an atom had been definitely split into two portions of equal size and it naturally received a good deal of publicity. Full investigation shews that here again the invader is captured with the result that:—

Lithium (7)+Proton (1)=Helium (4)+Helium (4)

The discovery in 1934 of a hitherto unsuspected isotope of Hydrogen with an atomic weight of 2, i.e., a Proton of twice the mass of any proton previously known, has raised hopes of still greater success. Lewis and Lawrence in California have succeeded in obtaining an electric potential of 10 million volts. With this terrific driving force and the double-mass proton as a projectile it is hoped to break up the more strongly guarded nuclei of the heavier elements.

When the disintegration of the atom occurs, whether it is the result of bombardment by α-particles or protons, the fragments fly in all directions like the explosion of a shrapnel shell. Naturally the individual pieces cannot be observed but their tracks can. Just as a meteor flashing across the night sky leaves a trail behind that indicates its path, so also in a Wilson cloud-chamber do the flying fragments of a shattered atom leave a visible trail which gives much information about them. When radioactivity gave the first indications of the existence of a great store of energy within the atom many fantastic statements were made of the dawn of a Utopian age when the locked doors of the atoms would be opened and their vast supplies of energy made

available for the use of mankind. No need of thousands of tons of coal or their equivalent in oil to take a liner across the Atlantic. The atomic energy of half a pound of coal would be sufficient! Experience has however dashed all such hopes. An atomic explosion is not like a T.N.T. one. In the latter case the explosion of a detonator in the mass of T.N.T. starts an action which spreads with great rapidity until in a moment almost, the whole has exploded. In the case of an atom there is no such effect. A million or so shots at random produce a single hit, the atom struck is affected but nothing happens to the myriads of others near at hand. As far as actual gain is concerned we have had to use a battery of artillery to shoot a rabbit. The cost of the ammunition is far away greater than the intrinsic value of the "bag." The great value of the feat lies in the knowledge that it can be done, that an ordinary atom has not the charmed life that was believed, that its nucleus is not proof against attack from outside and that transmutation of one element into another is a fact and not a wild dream. A base metal has not yet been transmuted into gold; there is no reason why it may not be done, but it will still probably be cheaper to buy the gold in the bullion market.

Two other discoveries in this field of research must be mentioned. The first is that of the "Neutron," by Chadwick at Cambridge in 1932. It was found that when Beryllium was bombarded by fast α-particles from Polonium a shower of particles of a new kind was obtained. They were like "Protons," except that they had no electric charge, and a proton without its positive charge was unknown. Their penetrating power was extraordinary, they passed through thick plates of metal with ease. Chadwick suggests that they are

protons with electrons much more closely associated with them than is the case in a Hydrogen atom, so closely in fact that they together behave as a single radiative unit. Because of the absence of electric charge they have been called "Neutrons." What is the secret of its great penetrating power? Let us picture an atom—a "+" charged nucleus surrounded by "–" charged electrons with empty space between. If a hostile electron approaches it is repelled by the planetary electron patrols because their electric charges are similar. A very high-velocity electron may be able to push aside the guard but its attack on the nucleus would be fruitless on account of their relative masses. An attacking Proton would be able to pass the electron guards but in face of a charge on the nucleus similar to its own would be repelled unless it had very high velocity and therefore high momentum. But a Neutron is not electrically charged, therefore neither the negative charges of the guarding electrons nor the positive ones of the nucleus can have any effect. It can pass through the intervening space with little if any restraint. Because of this what splendid projectiles they would make in the bombardment of a nucleus! The trouble is that there is no present means of firing them.

The second discovery was that by Blackett and Occkialini at Cambridge in 1933. We have already referred to the "Wilson Cloud Chamber." This is an ingenious piece of apparatus devised by C. T. R. Wilson of Cambridge. The principle of it can be briefly described. When air super-saturated with moisture is suddenly cooled the moisture is deposited. If there is dust or anything else in the air on which water droplets can form, the moisture produces a mist or cloud which slowly settles. Minute electrified particles such as

ionised atoms, electrons, protons, etc., can serve as the cores of the water droplets. In the Wilson chamber the air is freed from dust, supersaturated with moisture and suddenly cooled by expansion. Any ionised particles will then betray their presence by the formation of cloud tracks which can be illuminated and photographed. By this means the movement of the particles can be studied and can also be varied by electric and magnetic forces which can be applied to the chamber. The different forms of the tracks of electrons, protons, α-particles, etc., are well known. Blackett and Occhialini found some which were unlike any previously observed. They were precisely like those produced by electrons with the exception that magnetic forces *bent them in the opposite direction.* This could only mean that they have the *mass of an electron but a positive instead of a negative charge.* They have therefore been called "Positrons." There are thus electrons of two kinds, the better known ones negatively charged forming the planetary outer guard of all atoms and the more recently discovered positrons whose exact place in the atom is a matter of conjecture. There is also reason to believe that an electronic analogue of the neutron exists, i.e., a particle with the mass of an electron but no electric charge at all. The name "Neutrino" has been given to this.

When any quantity of a gas is compressed its bulk diminishes in proportion. This is the well-known "Boyle's Law." When the bulk has been reduced to very small amount further pressure does not produce a proportionate volume reduction. Compression is simply squeezing the molecules closer together. When the molecules are far apart as they are in a gas under ordinary conditions the space occupied by the molecules them-

selves and their mutual interactions are of little consequence. But when compression has brought them very close together they must be taken into account. We have pointed out that atoms and molecules are mainly "emptiness," it is the guarding planetary electrons that prevent too close an approach and set a limit to the degree of compression, and therefore to the *density of a substance*, for density is merely the measure of the amount of a substance that occupies unit space. If the protecting electrons could be removed atoms and molecules could approach each other much more closely, density therefore would be much increased. Can this be done? Where there are several electrons one or two can be expelled but no more by the means at our disposal. In the sun and stars, however, where temperatures and pressures exist far transcending anything we can produce there is reason to believe it is done. Spectroscopic evidence if rightly interpreted leads to the conclusion that in some stars known as "White Dwarfs" the atoms are completely stripped of their planetary electrons and the nuclei brought very close together. Consequently the density is very great indeed, so great that *a ton could be packed in an ordinary match-box.*

It may be useful to sum up this part of our subject :—

1°. The Ancients believed that all matter was made up of five primitive things, earth, air, water, fire and a mysterious "Materia Prima" whose nature was not defined. It was suggested later by Prout that the primitive material might be Hydrogen and that Allotropism might account for the rest.

2°. Modern discovery has reduced all matter to Protons, Neutrons, Electrons, Positrons.

3°. An atom is a complex system consisting of a Nucleus

possessing a definite positive electric charge and rings of planetary Electrons whose total negative electric charge is equal to and neutralizes that of the Nucleus.

4°. The mass (weight) of the atom is mainly in the Nucleus, its chemical properties are determined by the Nuclear Charge—or, what amounts to the same thing, the number of the planetary Electrons.

5°. The addition of Neutrons to the nucleus does not alter the Nuclear Charge—and therefore the chemical properties—but increases the Atomic Weight. This explains the occurrence of Isotopes.

6°. The group constituting the Helium Nucleus, i.e., 4 Protons and 2 Electrons, appears to be a very stable group. There are indications that such groups tend to form in the nuclei of all atoms; thus Carbon with atomic weight of 12 would have 3 of them whilst Oxygen with atomic weight 16 would have 4.

7°. Some of the planetary Electrons of an atom, generally 1 or 2, can be expelled by heat, electrical repulsion, impact with a high-velocity particle, etc. The atom is then "ionised" and has lost its characteristic chemical properties. An α-particle is an atom of Helium deprived of its 2 planetary electrons.

8°. By bombardment with high-velocity Protons and α-particles the Nuclei and Nuclear charges of many atoms have been changed, one element thereby being transmuted into another.

9°. When the bombardment is by α-particles the change is to the element of next-higher Atomic Number with the expulsion of a Proton. Thus Rutherford transmuted Nitrogen (Atomic No. 7) to Oxygen Isotope (Atomic No. 8).

10°. When the bombardment is by Protons the change is to the next lower Atomic Number. Thus Cockcroft and Walton transmuted Lithium (Atomic No. 3) to Helium (Atomic No. 2). This was a "splitting" of the atom because one atom of Lithium was changed into two atoms of Helium.

11°. By bombarding Beryllium Chadwick obtained Neutrons, high-penetrating particles with the mass of Protons but uncharged and therefore not impeded in their penetration of matter by the nuclear charges.

12°. The discovery of the Hydrogen isotope "Diplogen" with atomic weight 2 coupled with the high-voltages obtained by Lewis and Lawrence gives a projectile of great shattering power by means of which the more massive nuclei may be disrupted.

13°. Perhaps by this means the Alchemist's Dream may be fully realized, the transmutation of Lead to Gold, but it will have to be in stages, Lead to Thallium, Thallium to Mercury and Mercury to Gold. Gold so obtained would be precious indeed!

CHAPTER X

SOME OUTSTANDING PROBLEMS

THE statement is often made that never before was scientific progress so great as it is to-day. At a first glance this would seem to be true, a man of mature age might point to the great discoveries made in his lifetime as evidence of the truth of the statement. But on more careful consideration it is open to question. Looking at the matter in the proper perspective, putting ourselves in the position of a past-time observer we find that much the same could have been said by him. What an advance the telegraph must have seemed in the days when news had to travel by courier on horseback, or gas and paraffin oil in the age of tallow dips and colza! It is true that modern discoveries have followed one another with great rapidity, but we must remember that the general pace has quickened and probably the proportionate advance has not been much greater than in the past. With problems solved and difficulties swept aside it might be thought that the end was in sight, that nothing much remained to be done. Physical Nature however is very baffling. With every problem solved, every difficulty overcome, others present themselves, there seems to be no finality. It is like chasing the rainbow or trying to reach the horizon, we can get no nearer, try as we will.

With the discovery of the electron and proton coupled with their arrangement in the Rutherford-Bohr atom it seemed that at last the nature of Matter was settled. Moseley's Law of Atomic Numbers threw light on Mendeléeff's Law and settled its anomalies. Then

Chadwick dropped a bomb by discovering the Neutron, another was dropped by Blackett and Occhialini when they disclosed the Positron. What an exceedingly complex thing an atom really is! Is there anything else in it that may be found at any moment? We talk of "dead matter," "inert matter," and yet we find that every single atom is a veritable hive of industry, chock full of energy. Electrons are rushing round in their orbits, jumping from one orbit to another and in so doing emitting radiations that travel across Space with terrific velocities producing effects some of which we are only now beginning to detect. Far from having settled things we are now wondering if we shall ever discover all the details. The difficulties we once had about the atom are now transferred to the Nucleus. How is it constituted? What exactly are the parts played in it by its electrons, neutrons and positrons—and perhaps neutrinos? The more precise our methods of research, the more delicate and precise our instruments, the more do our troubles multiply. Already a new Wave Mechanics has been invented to deal with the intricate motions and other effects already known. And so the problem remains with us, time and the increasing army of research workers all over the world can alone find us answers to these many questions.

A. Cosmic Rays.

Since the discovery of Radium we have realized that we live in a world of Rays. All radioactive bodies emit them producing various effects, luminous, thermal, photo-electric, electric. There is no cessation of these emissions which are also coming from the minerals from which radioactive bodies are obtained. Some of the products of the disintegration are gaseous, escaping into

the air or being absorbed by water, especially that of deep springs. These gaseous products in their turn disintegrate and give rise to active solid deposits on objects in contact with them, such as Radium A, B and C, all of which are sources of very vigorous "Gamma" rays. A very effective way of detecting the rays is by means of a "Radio-electroscope" whose gold leaves are discharged in the presence of the rays. The intensity of the rays is measured by the rate of discharge of the Electroscope.

Using such an instrument it is found that at all times, in all places, and in all circumstances the rays are to be found. In the absence of any other known cause it was believed that the rays are due to natural radioactivity from radioactive minerals in the ground and their products in the air.

The natural conclusion was therefore that the further one could get away from the earth the less the effect would be. At various times during recent years and at many places this has been put to the test by, among others, McLennan, Rutherford, Gockel, Kolhörster, Millikan, and Bowen. Electroscopes taken up high mountains in districts far removed from known radioactive minerals shewed signs of stronger radiation than at lower levels. Sending up a self-recording instrument by balloon to a height of 28,000 feet Kolhörster found the radiation to be 7 times as great as at ground level. Millikan and Bowen sent one to a height of 10 miles with similar results. Instruments have been buried to great depths in Alpine glaciers and mountain lakes in California and Bolivia. In each case the story is the same, rays of intense penetrating power, able to pass through 50 feet or more of ice and water have been found. Recent measurements prove that they are much harder, i.e.,

shorter wave-length, than Gamma rays of radioactivity, their ability to penetrate ordinary solid matter being remarkable. *What are they? Where do they come from?* They have been called " Cosmic Rays." Owing to the inadequacy of accurate methods of determination it is impossible to say with certainty whether they are waves like light and X-rays, or streams of corpuscles travelling at very high speed. Both views have been held and there is evidence of sorts in support of both. Whatever they are there is no doubt of their existence. It was the Cosmic Rays that knocked Positrons out of Atoms in Blackett and Occhialimi's experiments.

Where do they come from? This too is an unsolved mystery. Different ideas have been put forward from time to time only to be abandoned when carefully tested. One idea was that they were the result of thunderstorm discharges in the atmosphere at high levels. Experiment shewed that they are quite as common in regions where thunderstorms hardly ever occur as in places where they are frequent. Auroral discharges have also been ruled out after investigation. Do they come from the sun? Here again day and night make no difference, not even the long periods of light and darkness in the Arctic. Excursions into the Stratosphere by Belgian and Russian observers have confirmed previous knowledge but given us nothing new.

Do they come from the stars, the " Milky Way," for instance? Here again careful investigation has given only negative results. No difference has been observed whatever position the Milky Way with its millions of stars may have.

Millikan considers their origin to be probably in those millions of recently discovered " Island Universes," the Extra-Galactic Nebulæ far away in outer space. As

there does not appear to be any means of putting the idea to the test we must be content with the bare record of it.

Apart from the place of origin of the rays there is the question of their cause. Is there anything known which might give rise to radiation of such a penetrating nature, able to penetrate with ease 12 feet of Lead? Two views have been put forward either of which might be true—or neither or both. Here we return to the composition or make-up of the atom. We have dealt at some length with this and have seen that every atom is made up of protons, electrons and the rest.

But when they are all totted up it is found that the total weight is slightly less than it should be. For example a Helium atom should weight 4·032, i.e., four times 1·008 (the weight of a Hydrogen atom), whereas it only weighs 4. It is suggested that the small difference—·032—has been converted into radiation. It is well known that radiation has weight, the pressure of light has been detected and measured. It is true it is small but it exists. Since Helium groups seem to be components of all atoms and since somewhere at some time these groups have been formed, a large amount of radiation has been emitted. The suggestion is that in the Extra-Galactic Nebulæ Helium atoms are being built up from Hydrogen atoms and the radiation set free reaches us as Cosmic Rays.

Another view is that Matter can be "annihilated" and an intense Radiation produced thereby. We have seen that the nuclei of atoms contain protons and electrons with their opposite electric charges. If these could come into actual contact there would be neutralisation and nothing would remain. The matter would be annihilated and an intense Radiation produced in its

place. This would be quite different from our ordinary ideas of destruction. As matter it would just *vanish.* And somewhere Cosmic Rays would appear. The conversion of Matter into Radiation and vice-versa, if confirmed, would help to solve other problems of the Universe such as the supply of energy to keep the Sun and the Stars going. At present we do not know for certain where the Sun's supply of heat and light come from. Certainly not from combustion. The Sun is much too hot to burn.

Therefore Cosmic Rays still remain an unsolved problem. They exist, they are more penetrating than anything else on earth, they may be responsible for many things for which a satisfactory cause has not been found. They may be the cause of radioactivity, applying a match to an explosive atom. What effect, too, have they on the atoms constituting the human body? At present there is no answer to this question.

B. *Catalysis.*

The inclusion of catalysis among the problems has been deemed justifiable although its widespread application to modern industrial processes may render this debatable. So little is known about what actually takes place in the majority of cases in spite of many theories about it that it may still be regarded as a "problem."

"Catalysis" may be defined as an effect produced by a substance that is out of all proportion to the amount of the substance employed; or as a chemical action that is accelerated or retarded by the presence of a substance that is not otherwise concerned with the changes taking place. The substance so acting is called a "Catalyst." An action that is retarded by a catalyst is called "Negative Catalysis."

It was formerly believed that catalysis was of exceptional occurrence but modern experience shews that it is very general and modern Industry has been quick to take advantage of it.

The fact that at the end of an operation the catalyst is the same in amount as at the beginning led to the view that it had been unchanged all the time, but that opinion is no longer held. In some cases there are indications both of a chemical and physical kind that suggest possible changes in it, in others any such indications are entirely absent. It ends, in amount at any rate, as it began.

A few examples will help in a better understanding of it :—

(*a*). One of the most vigorous actions known to Chemistry is the combination of Hydrogen with Oxygen to produce Water. When H and O in the proportions by volume of 2 to 1 is ignited or sparked or heated combination takes place with explosive violence. If however the gases are *perfectly dry* they refuse to combine. If a small trace of moisture is introduced into the mixture combination takes place at once. The small amount of moisture is a "Catalyst" and the action is "Catalysis." What part does the moisture play, what exactly does it do ?

(*b*). Suppose we want to dissolve a small piece of tin in Hydrochloric Acid, solution takes place it is true, but very slowly. If, however, a single drop of a solution of Platinum is added the action takes place with great vigour, is completed in a few minutes, and the Platinum is still present and can be removed. Suggested explanations such as "Electrolytic Action" though plausible are not altogether satisfactory. The Platinum acts as a Catalyst.

(*c*). A common constituent of cereal foods is Starch, which is not digestible as such. Before it can be assimilated by the body it must be converted into sugar

which is soluble. Unaided, this conversion is very slow. There is a substance present in Malt called "Diastase," which can act as a Catalyst, changing about 2,000 times its own weight of starch into soluble sugar, hence the use of Malted foods. Certain substances present in small amount in the digestive fluids such as the saliva behave in a similar way, acting as Catalysts end enabling the body to make use of indigestible materials.

(*d*). Mention has already been made of the manufacture and composition of the gas mantle. The active substance giving the incandescence is "Thoria," an oxide of Thorium. If a small quantity of "Ceria," an oxide of Cerium is added the brilliance of the incandescence is considerably increased. It is not due to any added brilliance of the Ceria which is little, if any, greater than that of Thoria. The amount required is very small, only about 1 %. To use more or less defeats the purpose. It is an instance of Catalysis, the Ceria being the Catalyst. If we enquire what precisely takes place there is no satisfactory answer.

(*e*). We hear a great deal nowadays about "Vitamins," substances present in various foods in almost infinitesimal quantities which have an astonishing effect on bodily nutrition. The writer suggests—with some diffidence—that they are Catalysts, as are probably the secretions of some of the bodily glands, able to assist the body to take advantage of materials for its sustenance.

Catalysis in Industry.—

A few examples are here given of the application of catalytic action in large-scale industrial operations:

1. *The manufacture of Sulphuric Acid (Oil of Vitriol).*

It has been stated that the industrial prosperity of a

nation can be measured in terms of the quantity of Sulphuric Acid it uses. It is required for so many manufacturing purposes that there is probably some truth in the statement.

Theoretically, Sulphuric Acid (H_2SO_4) is easily produced; the only things needed are Sulphur Trioxide (SO_3) and water. To get SO_3 we need Sulphur or some mineral containing it such as Iron Pyrites, and Oxygen which the air can supply. But we find that Sulphur has a great objection to form SO_3 by direct union. It will form Sulphur Dioxide (SO_2) readily, merely burning it in air will suffice, but although the Oxygen is present in abundance it refuses to combine with any more. The use of a Catalyst makes the apparently impossible easily accomplished. Several Catalysts may be used but the most efficient one is Platinum in a finely divided condition. If the SO_2 and Oxygen are made to pass over the finely divided Platinum they combine at once and SO_3 is produced. The platinum is unchanged and can be used over and over again. What precisely does it do? That is the unexplained mystery.

Another curious fact may be mentioned here; the Catalyst can be poisoned! If certain substances are present it is dead, inert; such substances being called "Catalyst Poisons." The presence of quite a small amount of Arsenic renders the Platinum inactive or "dead." With the removal of the Arsenic the Platinum becomes active again as before. Since Arsenic is a common impurity in Sulphur minerals care has to be taken to eliminate it before using it for this purpose.

2. *The Hydrogenation of Fats.*

The world-demand for solid fats, required for the manufacture of Soap among other things, is much in

excess of the supply. On the other hand there is an abundance of fluid fats, vegetable oils such as linseed, olive, palm, Soya-bean, cotton-seed, pea-nut oils. Then again there is an enormous quantity of fish oil, such as whale oil and many oils from the other great fishing industries. But because of their fluid condition they cannot be used for many of the purposes required. Moreover their cheapness is an added advantage from the industrial point of view.

The difference between a hard fat such as suet and a fluid oil such as olive oil is that the former contains six more atoms of Hydrogen in its molecule than does the latter. If therefore these necessary six atoms of H can be suitably introduced the fluid oil will become a hard fat. Without a Catalyst it cannot be done but with one, in this case Nickel, it is accomplished. Again, the Nickel has no part other than that of assisting in an action that otherwise would not take place, and is still there at the finish. Not only is the fluid fat hardened but at the same time any unpleasant odour it may have is destroyed so that the "fishiness" of fish oils is absent in the finished product. Many edible fats from Soya-bean, palm kernel and pea-nut oils are prepared in this way and a world-wide industry of great proportions has become established. There are many substances that may act as poisons to the Nickel catalyst and care has to be taken to ensure their absence.

3. *The fixation of Nitrogen.*

In the year 1800 the population of the world was about 800 millions, in 1900 it had reached about 1,730 millions, more than double, and if the increase goes on at the same rate it will be nearly 4,000 millions by the year 2,000. Without being unduly alarmist this points to the need

for increased cultivation to provide food and other requirements. Since all plant life needs Nitrogen in readily available form a more abundant and cheaper supply of Nitrogen fertilisers will be necessary. Our chief natural supplies come from South America and no other large supplies are known to exist.

Of late years much attention has been given to the problem of utilising the vast supply of atmospheric Nitrogen. It will be remembered that Nitrogen is an inactive element which does not readily combine directly. It is Nitrates, either soluble or easily rendered soluble by action in the soil, that are required. One method of producing them is by means of the electric furnace, in which case the cost is controlled by that of electric current. Another method makes use of Calcium Carbide which again involves electricity.

A modern Catalytic process gives great promise of success. What is of importance is not so much the production of the Nitrates, that is accomplished, but their cheapness. It is claimed that the Catalytic method can produce what is required both in quantity and cheaply. Work in this country has been established at Billingham in N.E. England, in which many thousands of workers are engaged and hundreds of thousands of tons of fertilisers turned out. There are two main stages in the process. In the first Nitrogen and Hydrogen are made to combine, with the help of Iron as a Catalyst, to produce Ammonia. This is done by heating them under high pressure in steel bombs. The second process is the conversion of the Ammonia into Nitrates by oxidation with the help of Platinum as Catalyst.

Large scale experiments made by agricultural experts using the fertilisers shew that the yield of produce can be more than doubled.

The synthetic production of a great number of substances in everyday use has been made possible by the widespread application of catalytic processes in large-scale operations. Among many such products mention may be made of Graphite (Blacklead), Artificial Rubber, Light Oils such as Petrol from the Heavy Oils of Petroleum, similar Oils from Coal and Sulphur from waste.

C. *Gravitation.*

Everyone is acquainted with the sensation of weight. We support a body and feel a pressure; we remove the support and the body falls. There is no exception, apparent ones such as the upward tug of a balloon are due to other causes. Everything, great or small, is subject to the same tendency. *Everything behaves as if a force is dragging it to earth.* Philosophers have maintained, and some still do, that there is no such thing as "Force," but the ordinary man knows quite well the meaning of the word, what the effect of a pull or a resistance is and expresses it in terms of Force which can be accurately measured and stated in definite units. In this sense therefore we can say that the Earth exerts a Force drawing everything to itself which is known as "Gravitation" or the Force of Gravity. Its amount can be measured in various ways and is found to be such as to cause a freely falling body to have an acceleration of roughly 32 feet per second, i.e., to have its velocity increased during each second of its fall by 32 feet per second. Accurate measurements can be made with Attwood's machine or by the rate of swing of a freely vibrating pendulum.

We owe to Galileo the disproof of the fallacy that heavy bodies fall more rapidly than light ones. So firmly

rooted was this belief that even when he shewed it to be incorrect, by dropping different weights from the Tower of Pisa the onlookers were not convinced but thought they were the victims of a trick. How difficult it is to uproot an established belief!

That Gravitation is not the unique property of the earth, but is universal, was shewn by Sir Isaac Newton following on the investigations of John Kepler. For something like 1,500 years the Earth had been regarded as the centre of the Universe, the apparent motions of the heavens being accepted as the actual motions. During the centuries all the movements had been closely studied and "Laws" in agreement with them had been worked out. There appeared to be no reason to doubt their accuracy. It is true they were very complicated but they served their purpose. In the 16th and 17th centuries Copernicus and Kepler showed that the laws would be much simplified by taking the Sun as the centre of our planetary system. After much opposition the "Copernican System" was accepted towards the close of the 17th Century.

Studying the motion of the moon as it revolves in its monthly journey round the earth, Newton found that by regarding it as a freely falling body continuously falling towards the earth, coupled with a motion of translation of its own, its movements could be accounted for. From this the universal "Law of Gravitation" that will ever be associated with the name of Newton was evolved. It states that all bodies at all times in all circumstances attract each other with forces *directly proportionate to their masses and inversely proportional to the squares of their distances apart.* Many experiments have been performed that help to confirm the Law, the well-known Cavendish Experiment for instance. A

large mountain mass causes a long plumb-line near it to incline slightly out of the vertical towards it.

The movements of all the heavenly bodies whose motions are measurable, the planets about the Sun, the satellites about their primaries, the Comets, are expressed in terms of the Law. The attraction is of course mutual, each attracts the other, therefore the statement that one body moves round the other is not quite correct; each moves round their Common Centre of Gravity which is nearer the more massive member of the system and may even be within its body, as in the case of the Sun, whose mass is greater than that of all the planets put together.

The questions might be asked "If Gravitation is so universal why are things as they are? Why do things ever remain apart? Why doesn't all the air in a room concentrate into one compact mass? Why do not all the electrons in an atom rush into the nucleus? The answer is that all these things would happen if there were nothing preventing. Air particles and electrons have motions of their own which counteract or modify gravitational effects. Fortunately for us only the lightest and most rapidly moving components of the atmosphere are able to get away, the others which are the ones we need are held down near the surface of the earth by its gravitational pull.

Gravitation is a "Mass Action" exerted by all the individual particles against each other, the observed effect being the sum total of all the individual effects. In the case of the Earth we regard the attraction as directed to the centre as representing the effect of all the attractions summed together. This depends on its uniformity of constitution but is probably not far from the truth.

The important questions we must now ask are "How is this attractive force exerted?" "How does the Sun

maintain its sway over its furthest planet more than 3,000 million miles away ?" "What is the connecting link ?" We can understand a pull when there is a tow-rope and we cannot when there isn't. Here then is the "Problem." Effects of immense importance in the Universe assigned to a cause but with no easily explainable connexion between them. To merely give it a name and call it Gravitation is not to explain anything. A "strain" in the aether is suggested in which case it must take time to travel. But in the present state of our knowledge we have no means of testing this. We can measure the speed of light because we can interrupt it by a shutter. Roemer's shutter was the planet Jupiter. If we could find a screen of some sort that would cut off gravitation we could settle the question, but nothing of the kind is known. Writers of fiction have done it but have not let us into the secret. Science at present is helpless and the mechanism of gravitation remains an unsolved Problem.

CHAPTER XI

RELATIVITY

NOTHING in recent years has been so much discussed or written about in the daily and periodical Press as Einstein's "Principle of Relativity." Its greatest exponent in this country is Eddington, of Cambridge, but many others, such as Jeffery, Dingle, Russell have written on it, to all of whom the present writer acknowledges his indebtedness.

The subject is one which cannot be fully dealt with except with the aid of fairly advanced Mathematics and those readers with the requisite mathematical knowledge are recommended to consult more advanced works. They might very well start with Eddington's "Space, Time and Gravitation."

It is possible nevertheless to get an outline conception of it without Mathematics and it is the object of this chapter to attempt the task.

An understanding of Relativity has been obscured by misconceptions which we will try to remove. The word itself, Relativity, is partly responsible and a more suitable one might have been selected. There is a widespread idea that Einstein has set out to prove that movements, masses, lengths, etc., are "Relative." There was no need to do that, we knew it quite well already, we make constant use of the idea in our everyday life in a subconscious way. Short or long, big or little, quick or slow, all have very different meanings according to what happens to be in our minds at the time. We are well aware that if we say that a ship is travelling at 20 knots we mean its speed through the water irrespective of what

the water may be doing. An airplane travelling at 50 miles an hour through the air may be stationary relative to the ground. We know all this quite well although we do not call attention to it in our conversation, there is no need, it is understood. What Einstein set out to do was not to introduce complexity into our ideas but to simplify, to replace confusion by law and order.

Difficulty has been experienced through the use of unfamiliar expressions such as "Frames of Reference." If we substitute for it "Standpoint" or "Point of View" much of the difficulty will disappear. An illustration that has been much quoted will help. Picture a railway train travelling at 60 miles an hour with two people, A and B, in one of the compartments. A third passenger, C, is walking to and fro along the corridor. A says to B, "What is the speed of that man?" B, taking out his watch presently replies, "Two miles an hour." With all the data available what would a man standing by the railway track reply? He might say "The train is doing 60, the passenger is doing 2 in the corridor, therefore his speed is 62 or 58, depending on his direction." What would a man on the Sun say? Something like this: "The earth is travelling in its orbit at about 70,000 miles an hour, the train 60, the man 2, therefore his speed is about 70,062. An inhabitant of the star Sirius would give a much bigger figure because he would have to add the velocity of the Solar System in Space. What then is the speed of C? Obviously no unqualified answer can be given, it depends on the point of view or "Frame of Reference." This applies not only to velocities but to other measurements. Take another example with the train: Suppose A drops a pebble from the middle of the roof of his compartment on to the floor and asks B to observe its flight. B sees it hit the middle of the floor

and declares that it falls in a straight line. The man on the railway track says it describes a " Parabola " like a bullet shot from a gun. The Solarian, taking into account the earth's rotation and revolution would describe its path as a complicated spiral and the man on Sirius a still more complex curve. And *each of them would be right*—from his point of view. Are all measurements and estimates " Relative " to something and indeterminate unless a Frame of Reference is supplied ? What about Time ? Surely an hour is an hour in any circumstances ! Let us take another example. An aeroplane travelling at 60 miles an hour, with pilot and passenger, passes over Big Ben as it is striking 12 noon and the passenger sets his watch. After a while the pilot hearing Big Ben chime the quarter remarks that they have been travelling 15 minutes. The passenger looking at his watch says " No, it is now 16 minutes 22 seconds past 12. During the quarter-hour the plane has travelled 15 miles and it takes 82 seconds for the sound of the chime to reach them, for the plane has 15 miles start. If the passenger had no watch their estimate of time would have been wrong. Even if the passenger had a telescope and could see Big Ben there would have been an error—too small to detect in this case—because light also takes time to travel. In astronomical happenings the velocity of light conveying information must be taken into account.

Scientific " Laws " are generalisations based on the observation of phenomena. In certain circumstances under certain conditions certain things occur. A scientific law merely states this in concise form. Since the conclusions drawn from the observations depend on the view-point so must the Laws also. Let us consider the movement of a Planet. We observe the following phenomena :

(*a*) Its velocity varies but there is a sequence in the variations.

(*b*) Sometimes it appears to stop in its track, turn back for a while and then resume its former movement.

(*c*) Sometimes it is high in the heavens at others quite low, near the horizon.

How are we to group these together and formulate a general law that will enable us to calculate with reasonable accuracy its position at any future time ?

In the 2nd century Ptolemy, taking as his view-point the Earth which he regarded as stationary, drew up a scheme which was known as the " Ptolemaic System." During succeeding centuries as more precise measurements were made the " System " became more elaborated. By the inclusion of more " Cycles," " Epicycles," " Deferents," the " Laws of Motion " of the heavens became so perfected that for about 1,500 years nobody questioned their validity. The important point is that *they were all that any scientific Law ever is*, they were generalisations by means of which all that was known about the heavens could be adequately explained. They worked.

In the 17th century these " Laws " were all swept away. Galileo and Kepler shewed that by adopting another view-point, the Sun, and regarding it as stationary as suggested by Copernicus in the 16th century, a much simpler set of " Laws " could be found. It took nearly a century to get them accepted because until Kepler substituted elliptic orbits with the Sun at a focus for Copernicus' idea of circular orbits with the Sun at the centre, the new Laws were not as good as the old ones. Then Newton shewed that the Laws are in accordance with Gravitation so the " Copernican System " is

established and its Laws are the ones on which we rely.

Suppose an inhabitant of Jupiter chose to take it as his view-point, if he were a mathematician he could draw up a set of Laws based on a stationary Jupiter and would have a "Jovian System."

Each of these sets of Laws is valid for its own "Frame of Reference" but for no other. Therefore there must be as many systems of Laws as there are Frames of Reference with an observer in each.

Is it possible to evolve a set of Laws that will be valid for an observer wherever he may be? Einstein says "YES." The Principle of Relativity is Einstein's solution of what seemed an insoluble problem.

Relativity had its origin in the famous experiment first performed in America in 1887 and frequently repeated more recently by others with more refined apparatus. The object of the experiment was to measure the velocity of the Earth's movement in Space. We can measure the speed of a train if we travel in it and note the mile-posts. But we couldn't if the mile-posts were running about. The only mile-posts in Space, Sun, Stars, Planets are all running about. What then can we use? The aether perhaps. If a submerged submarine is travelling through the water at 10 miles an hour we could quite well regard it as stationary and the water moving past it at 10 miles an hour. When travelling in an express train we see the landscape rushing by. If Space is filled with the aether the Earth is much like the submerged submarine and the aether is rushing past it. How can this be measured? Let us picture a river and a swimmer. On the river bank two marks have been made a mile apart, the swimmer can do 4 miles an hour and the rate of the stream is 2. The swimmer swims between the two marks upstream and back, the time being accurately taken. The river is one

mile wide and the swimmer swims across and back. When the times are compared it is found that the journey upstream and back takes longer than the cross journey and both require more time than in still water. Moreover, if the differences in time are known and the speed of the current is unknown it can be calculated. It seemed that here was a means of measuring the "aether drift" provided the necessary "swimmer" could be found. In the Michelson-Morley experiment in 1887 the swimmer was a beam of light. An apparatus of great delicacy was arranged whereby a beam of light could be sent to a distant mirror and reflected back again to its starting-point. At the same time and in the same manner part of the beam was dispatched in a direction at right-angles to the first. When the two reflected beams are received any lag in time by either will produce diffraction bands which can easily be seen and photographed. The apparatus was so designed that it was capable of detecting much smaller differences than would be expected. In principle the experiment was quite simple, if one mirror was pointed upstream, i.e., in the direction of the aether drift, the other must be "Across stream." There was no means of knowing where "Upstream" was but by repeating the experiment frequently during a period of several months there was bound to occur an upstream time. *But no difference in time was found.* The experiment has been repeated frequently with the most elaborate apparatus that could be devised, with every imaginable precaution against possible error, but the result is always the same, *there is no difference between the times in the direction of the aether drift and across it.* Naturally this has been a great disappointment. The facts are perfectly plain. There must be a reason. What is it? Several have been suggested :—

(*a*) The effect is too small for the apparatus to detect. It has been shewn that such is not the case.

(*b*) There is no aether therefore there cannot be any aether drift. Even this should make no difference for we know that light takes time to travel in whatever way it does travel and so the diffraction would occur.

(*c*) The aether near the earth is bound to it and travels with it, in the same way as the atmosphere is bound to it and travels with it, therefore there is no " drift " through it by the apparatus. This has been fully considered and a definite negative conclusion reached.

(*d*) The " Contraction " explanation first suggested by Fitzgerald, supported by Lorentz and others, was that measurements are less in the direction of motion and therefore that Nature conspired successfully to defeat the experiment.

This gives the first of many shocks to our prevailing ideas. Isn't a yard always a yard, a quart always a quart? No, and Yes. If it is travelling in our direction, No; if we are travelling with it, Yes. And both judged from our own view-point.

It is at this stage that Einstein makes his statement, which is at the root of the Principle of Relativity, that *it is impossible by any physical measurement to measure absolute motion in Space.* That whatever we do, however we do it, we shall always find that Nature defeats us. Our Laws, our deductions, our conclusions, our measurements are only valid in our own Frame of Reference, from our own view-point, and as our view-point changes so does everything else.

Is there no way out? Are we for ever to be in a state of indefiniteness, unable to communicate our ideas,

results and measurements to one another because we cannot be in our own shoes and somebody else's at the same time?

Einstein says the difficulty arises because we think we are doing one thing when we are really doing something else. We think we are living in a world of Three Dimensions when in reality we are living in one of Four.

A little parable may be of use here. Once upon a time there was a highly intelligent caterpillar living in a garden with beautiful flat lawns and paths. He was of a mathematical turn of mind and used to amuse himself by drawing triangles on the paths and measuring their angles. Measuring the angles very carefully he found that the three angles always added up to two right-angles (180°). One day a bird picked him up, flew off with him and dropped him on the dome of St. Paul's. When he recovered from the shock, having brought his instruments with him, he indulged in his usual amusement. But he received another shock! In none of his triangles did the angles sum up to two right-angles! Whilst he was wondering about it another caterpillar came up and greeted him. "What is the matter," said No. 2; "you look very worried." I am worried," said No. 1; "just have a look at all these triangles I have drawn, and in every case their angles will not add up to two right-angles." "You silly fellow," said No. 2. "I have lived here all my life and have never yet found a triangle whose angles add up to two right-angles."

What would our No. 1 caterpillar think? Would he realize that previously he had been on a flat surface whereas he was now on a spherical one *and didn't know it?*

According to Einstein that is pretty much our position. We think we are in a world of three dimensions and that three-dimensional measurements are sufficient for all

our affairs whereas our world is a four-dimensional one and if we will only recognise that fact and make our calculations accordingly, all our difficulties will disappear. There will be no need for different sets of Laws owing to the different view-points of the different observers, one set of Laws will suffice for all.

Trouble arises however owing to a misunderstanding of the term "Fourth Dimension." Some seem to think that it means a mysterious world whose inhabitants possess senses and powers transcending ours whereas it is merely a "Mathematical Term." If we wish to tie a knot at a particular spot in a piece of string *one measurement* is sufficient to locate the exact place. There is only *One Dimension.*

To locate a ball on a tennis court *Two Measurements* are necessary, one from the base-line another from the side-line; or one from each of two corners; or from any two other known points. At any rate there must be the two measurements to locate the exact spot. There are *Two Dimensions.*

To locate a lamp hanging from the ceiling of a room *Three Measurements* are necessary. We may take them as we like, making our own choice of starting points but we must have the three measurements and three are sufficient. There are *Three Dimensions.*

Hitherto we have described everything, measured everything, considered everything, expressed our Laws about everything in terms of Three Dimensions with the result that we have had to alter everything as our view-point has altered.

According to Einstein there is another Dimension that we ought to have taken into consideration. If we had done this and made *Four Measurements* instead of three the difficulties and confusion would not have arisen.

That in order to locate any Event we must have the four measurements. The *Fourth Dimension is Time*, and the four-dimensional world in which we really live and in which everything really happens is a combination of Space and Time which has been called "Space-Time," or the "Space-Time Continuum." There is really nothing to be afraid of in the expression, it merely denotes that in all our estimates and measurements of the relationship between happenings or events both Space and Time are involved in Combination; that Time is not an independent entity unconcerned with Space but is involved in all material affairs.

Space-Time then is to be considered as a whole and an event regarded as occurring in it. It may be divided up differently by different "observers." We can divide up an area of 16 square feet in different ways. We might have it as a strip 8 ft. by 2 ft., or a square of 4 ft. side. Somewhat similarly an event expressed in Space-Time measure would be regarded as one Space and Time by one observer and as a different Space and Time by another, but the Space-Time value would be the same for both.

All our existing Laws are expressed in terms of Three Dimensions only, Time is left out, or when brought in is regarded as something quite independent. Estimates of space, masses, times are different for different observers, they depend on what the observers are doing. One who is travelling at 100 miles a second will have a different Space and Time from another who is travelling at 1,000 miles a second. What one observer calls a yard another may call a mile, what one calls a minute another may call an hour. Both may be right or both wrong, each would claim that he is right and the other wrong and there is no means of settling the matter.

A rod 1 yard long is to be measured by three different

observers, "A," "B," "C." We are not concerned with their methods but must assume they are adequate for the purpose. Suppose "A" is travelling with the rod; to him its length will be 3 feet. Suppose "B's" speed relative to the rod is half the velocity of light (93,000 miles a second). To him the rod would seem about 5 inches less. If "C" has a relative motion of 161,000 miles a second his estimate of the length would be half a yard. *And all are equally right.* Other measures are subject to similar uncertainties, Mass for instance. A mass of 1 pound weight may appear to an observer many pounds, even tons. It all depends on his position relative to it.

These ideas are certainly revolutionary and there is little wonder that there has been reluctance in accepting them. It is unfortuate that they are incapable of con-conclusive proof of a direct character, but there is abundant support for them indirectly.

We are compelled to face facts as they are whether we like it or not. Discoveries made in recent times demand an explanation. Masses of a minuteness formerly undreamt of are now well known. Alpha and Beta particles travelling at thousands of miles a second are being studied the world over. Distant Worlds and Universes of an immensity previously unknown, buried in the profundity of a Space seemingly boundless, travelling, rotating, revolving at speeds of hundreds of miles a second are now being investigated.

The old Laws when applied to explain the new facts are found wanting. Relativity does it better. That is the justification of Relativity, the only one at present. The old mechanics and mathematics sufficed for the old knowledge but the new discoveries of Natural Science demand a new mechanics and mathematics which so far

is only supplied by Relativity. And that is why we have had to wait for the 20th century and Einstein, why the discovery was not made by the Great Minds of the past.

Two examples may be given of the superiority of Relativity over the older methods of dealing with a problem of the Universe. The planets revolve about the Sun at certain speeds, distances and in times connected together by Kepler's Laws and Newton's Law of Gravitation in such a way that their positions at any time can be deduced provided that certain well-known errors are taken into account. The Gravitation Law of Newton states that the attraction between two bodies varies as their Masses. What Masses? Those at rest or in motion? Relativity has shewn that these are different but not appreciably so except at high speeds. When the position of the planet Mercury is calculated there is always a slight, but known, difference between calculation and observation, which can not be accounted for on the old system. But Mercury is travelling at about 30 miles a second, a by no means negligible speed. Einstein used a corrected value for gravitation and *the error disappears.*

Relativity requires that a ray of light passing near a massive body shall be deviated towards it by a certain amount. In May, 1919, an eclipse of the Sun provided a means of testing this claim. At the time of totality certain stars were in such a position that their light in reaching the earth would have to pass near the Sun. If Einstein was right the light would be deviated and the stars would appear displaced. Observers were sent to West Africa some months before the eclipse to photograph the particular stars and note their positions. Photographs of the same stars taken during the eclipse *shewed the deviation that Relativity required.*

It might now be asked "How does Relativity affect us in our ordinary everyday lives?" Not much. So long as we are at rest relative to the thing we are observing our measures are as of old, a yard is still 3 feet, an hour is still 60 minutes. Even travelling at speeds which would seem very high in our relations with our fellow men there is no measurable difference. The diameter of the Earth which is travelling at about 18 miles a second would only be reduced by a few inches. Therefore Relativity does not concern us in our ordinary affairs. It is only when we have velocities of hundreds and thousands of miles a second that masses, spaces and times become changed in our Three Dimensional estimates of them.

We may summarize briefly :—

1°. We must not suppose that Newton was wrong in his laws of motion and gravitation. He was quite right with the data at his disposal and his work will stand out for all time as that of a genius.

2°. Since Newton's day Science has made great progress and facts have come to our knowledge which, if he had known them, would have caused him to remodel his famous Laws.

3°. It is impossible with our present knowledge to measure absolute motion in Space because we do not know of any fixed standard of comparison. Everything is moving relative to everything else and we do not know what the absolute movements would be.

4°. The three measurements to which we are accustomed are not sufficient to locate an "event," we must have a fourth, Time, i.e., we must add "Before and After," or "Sooner and Later" to our previous

measurements. In other words Space is "Four-Dimensional" not "Three-Dimensional" as we have hitherto supposed.

5°. Four-Dimensional Space does not mean another kind of world transcending this one in which beings possess transcendant powers. It is merely a Mathematical term implying the need for four measurements to locate any particular event.

6°. Just as an area may result from the combination of various lengths and breadths, so any particular Space-Time may result from various Spaces and Times.

7°. Space-Time measurement of any event is the same for all observers whatever they may be doing.

8°. Each observer divides the Space-Time in his own way into so much Space and so much Time, therefore one man's Space and Time are quite different from those of another.

9°. Following from 8°, what is 1 foot to one observer might be 1 yard to another travelling at a different rate; an hour to one may be only a second to another.

10°. For all measurements on the earth the older methods will serve because there any possible relative motion is of no consequence.

11°. For all moderate relative velocities the older methods will suffice.

12°. For velocities in inter-stellar space, for Alpha and Beta rays, etc., "Relativity" is operative.

13°. At high velocities Mass, Gravitation and Physical values generally are dependent on velocity.

14°. Relativity has received confirmation from the perturbations of the planet Mercury, from the gravitational deviation of light and in other ways.

15°. The statement that no velocity greater than that of light is possible has proved a stumbling block to many. If it is remembered that Mass increases with relative velocity at a much greater rate than does the velocity and that at the velocity of light Mass becomes infinite the difficulty should disappear, for an infinite Mass cannot have its velocity increased, otherwise the Mass would also have to increase, which is impossible.

CHAPTER XII

MINERAL OILS

An " Oil " is a liquid generally not miscible with water. When obtained from the earth it is known as a " Mineral Oil " as distinguished from the many others derived from animal and vegetable sources, although that was probably their ultimate origin.

We have already seen that during the Carboniferous and Tertiary periods of the earth's history a prolific vegetation flourished in the climatic conditions then existing. Tropical temperature, much moisture, an atmosphere containing a much higher proportion of carbon dioxide, all combined to provide the basic material from which our coalfields have been formed. At the same time by reducing the amount of carbon dioxide in the air and replacing it with oxygen the vegetable life of the period rendered the air suitable for animal life as it is to-day. The subsequent decay of this vegetation under conditions already described brought about our existing coal supplies.

There is no doubt whatever as to the ultimate origin of coal, what doubt there is concerns the details of the subsequent changes.

The origin of Mineral Oils is less certain, several theories have been put forward but we may quite well reduce them to two—the Inorganic and the Organic.

The Inorganic theory is that it has been formed deep down in the earth by the chemical action of water—probably in the form of steam—on those compounds of Carbon with metals known as Metallic Carbides. Calcium Carbide is one of them and it is well known that

the action of water on it is to produce Acetylene, a highly inflammable Hydrocarbon usable as a fuel. It is a fact that the action of water, especially in the form of steam and under the high pressure that would exist at great depths would produce mineral oils. What is not certain is the existence of the Carbides. There is no reason why they should not exist but that is not proof that they do. We know so little about the earth at great depths, we have only scratched the surface. A serious objection to the theory is the existence of strata, capable of bearing oil but containing none, below others in which oil is found. This suggests that it is not forced in from below but produced where it is found. Nevertheless the fact that some chemists of note support the theory makes us reluctant to discard it.

The Organic theory has much more general support from oil prospectors and those in close touch with the industry. According to it oil has a similar origin to that of coal. The climatic conditions which fostered a profuse vegetation on land would also encourage a luxuriant marine vegetation in the warm, shallow seas that covered much of the earth's surface. This would die down and fall into the ooze of the sea bed to lie there and slowly decay along with the remains of the lowly organisms that lived in the waters. The process of decay would be different from that of the land vegetation owing to the action of the salt and the absence of air. Age succeeding age the deposits would accumulate, the sandy, calcareous ooze containing the decaying organic matter would consolidate. Subjected to pressure above and to heat below a slow process of destructive distillation set in somewhat akin to that described in connexion with coal. If an impervious layer such as clay or close-grained shale happened to be formed above and below

the products of the action would be sealed up, unable to escape and would accumulate under pressure.

During subsequent ages owing to the earth's contraction the strata were crumpled and folded into a wave-like form the upper part or crest being known as an "Anticline" and the lower part or trough a "Syncline." We can picture the porous strata as holding the liquid products much as a sponge holds water, the lighter ones being forced into the anticlines, the heavier ones into the synclines. Gaseous products of which there are many would also tend to rise to the highest points, but being unable to escape through the sealing strata would be held in solution under pressure like the gas in a bottle of soda water.

There is very little doubt that in some districts oil supplies of small amount are derived from existing coal measures by a process of slow distillation.

Mineral oil has been known from early pre-Christian days in many parts of the world but was not in general use as a fuel or illuminant, rather it and the flames of the burning associated volatile substances were subjects of awe, reverence and superstition. Up to the middle of last century the oils in common use as illuminants were animal and vegetable ones such as Colza and Whale oils.

In 1847 an inflammable oil was discovered oozing from the ground in the mining district of Alfreton near the borders of Derbyshire and Yorkshire. A company was formed to collect and purify it, separating it into a light portion for which there was no use and a heavier portion which found a good market as a lubricant, especially for fast-running machinery whose bearings were liable to get hot and for which the common greases in use were not satisfactory. The fact that the light

distillate found a market in Germany led to the recognition of its good qualities as an illuminant in a suitable lamp. This marks the beginning of the mineral oil lamp era.

The Alfreton oil supply gave out in about three years. Expert opinion decided that it was derived from the slow distillation of coal or carboniferous shale and a search was made for a material that might yield an oil when subjected to such a process. This was found at Bathgate in the south of Scotland. Thus the Shale Oil industry was started and spread to other countries. Suitable carboniferous shales are found in many places, their yield of oil varies considerably, some giving nearly 100 gallons per ton whilst others give less than 20. Some, such as the Kimmeridge shales of Dorset, contain troublesome impurities, the removal of which increases the final cost, which is also influenced by the available and marketable by-products.

The discovery of large-scale supplies of naturally occurring mineral oil dates from 1859 when Col. Drake in Pennsylvania, boring for brine, tapped an oil-bearing stratum. This quickly led to a number of other wells being sunk in the district, but the yield was not great. These wells were not deep and it was not until greater depths were reached and supplies that seemed well-nigh inexhaustible were tapped that the American oil-boom set in.

We have pointed out that when the oil-saturated strata are sealed on all sides by impervious rocks the gaseous components are pent up under pressure like the gas in a soda water siphon. When the boring pierces the sealing strata the gases rush out carrying with them the oil and we have what is known as a " Gusher." In such circumstances there is a risk of much oil being lost. Millions of

gallons have been lost in this way owing to inability to cope with the outburst.

At first the chief demand was for those constituents that were suitable for use in lamps with wicks—paraffin oil lamps—and for lubrication of machinery, the demand was unequal consequently there was waste. When the internal combustion engine was invented about 1878, first for use with coal gas and afterwards with oil, a more equalised demand arose with subsequent benefit to the industry; a use had been found for a previously useless residuum.

Up to this time America was the chief source of oil, but now prospecting on a wider scale commenced and world-supplies were opened up.

Oil is usually found in porous strata, limestone, dolomite, sandstone, conglomerate, between impervious strata such as close-grained shale. The district is generally mountainous owing to the folding of the strata by lateral compression of the contracting earth. The upper parts—the Anticlines—will contain the lighter constituents and the lower portions—the Synclines—the heavier components, all containing gas in solution under pressure.

The oilfields of the world may be divided into East and West. In the West there are the vast supplies of the United States, Mexico, Canada and West Indies. In the East there is Russia whose supplies are chiefly concentrated in the Caspian Sea district in the neighbourhood of Baku. Then there is the region of the Caucasus. Further south the Carpathian area includes the oil districts of Galicia, Roumania, Hungary. Going further East there are Persia and Mesopotamia. Still further, in the Dutch East Indies, Java, Sumatra and Borneo, all have valuable supplies. The Indian Empire is rich in oil, Burma

especially so, whilst other British Dominions such as Australia, New Zealand, and parts of Africa can contribute to the general world-supply. This is by no means a complete survey, but it will suffice to shew how widespread is the distribution of oil.

The crude oil is a mixture of hydrocarbons in number varying considerably but reaching in some cases nearly thirty. The number and nature depend to some extent on geological conditions, whether for instance any fracture in the sealing strata has allowed some to escape.

Once the pressure of imprisoned gases is relieved the oil is obtained by pumping, baling or by compressed air. In some districts it contains much sand in which case pumps are liable to damage. A baler may be then employed, lowered into the well and hauled out, or, if cost will allow it, the boring may be lined with an airtight casing and the oil forced out by compressed air.

As obtained it is a dark, almost black, viscous fluid which is conveyed by pipe-line to the place where it is to be stored and refined, the preliminary storing allowing the sand and water to settle, the final separation or "Refining" being done by distillation.

In Chapter VII we referred briefly to the Paraffin and Olefine series of hydrocarbons. We must here extend the list a little. The Paraffin series is that whose general formula is $C_N\ H_{2N\ +\ 2}$, as follows:—

Methane .	CH_4	
Ethane .	C_2H_6	gases
Propane .	C_3H_8	
Butane .	C_4H_{10}	
Pentane .	C_5H_{12}	B.P. 38° C.
Hexane .	C_6H_{14}	B.P. 70° C.
Heptane .	C_7H_{16}	B.P. 99° C.
Octane .	C_8H_{18}	B.P. 124° C.

Nonane .	C_9H_{20}	B.P. 148° C.
Decane .	$C_{10}H_{22}$	
Undecane .	$C_{11}H_{24}$	
etc., etc.	etc., etc.	

The subsequent names are all given by the number of Carbon atoms as a prefix followed by the syllable " Ane." The first four are gases. Pentane is a liquid boiling at 38° C. Up to about $C_{19}H_{40}$ they are liquids gradually becoming viscous, above this they are solid.

The other series already mentioned, the Olefine Series has the general formula C_NH_{2N} as follows :—

Ethylene .	C_2H_4	gases
Propylene .	C_3H_6	gases
Butylene .	C_4H_8	gases
Amylene .	C_5H_{10}	B.P. 39° C.
Hexylene .	C_6H_{12}	B.P. 67° C.
Heptylene .	C_7H_{14}	B.P. 95° C.
Octylene .	C_8H_{16}	B.P. 125° C.
etc., etc.		

The subsequent names are given by the number of Carbon atoms as a prefix followed by the syllable " Ylene." The division into gases, liquids and solids is much the same as in the Paraffin series.

In the petroleums of the West members of the Paraffin series predominate, in the East the Olefines are found in greatest quantity. In some districts fracture of the overlying strata has allowed the more volatile portions to escape. Beds of Ozokerite or natural Wax and of Bitumen or natural Pitch have arisen in this way.

The " Refining " of petroleum consists in separating by simple distillation the complex mixture of hydrocarbons into fractions suitable for general requirements. It is not necessary to make an absolute separation of each

individual hydrocarbon, although by redistillation a finer grading is effected when required. Roughly, what is done is the separation into Motor Spirit; Naphthas for many industrial purposes; Burning Oils known as paraffin oils in this country; Heavy Oils for gas making, lubrication and Diesel-type machinery; Vaselines and Waxes. The gaseous fractions are stored for gas illumination and for the removal of any Helium they may contain.

The separation here outlined means that the members C_6, C_7 and perhaps C_8 will give motor spirit of various grades depending on the quantity of each present, volatility diminishing with increase of C. Fractions containing C_8 and C_9 will be classed as naphthas, commercially valuable for their solvent qualities. Illuminating oils (paraffin oil) must be fluid enough to readily pass up a wick but not so volatile as to gasify easily and tend to explode. Such oils will begin at C_{10} and extend to about C_{15} or C_{16}. The Heavy oils will extend to about C_{19} beyond which are the solids (Vaselines and Waxes).

It must be understood that we have here a rough separation regulated by commercial requirements and capable of any degree of variation as the need may arise. Each of these commercial fractions may be further refined for other purposes such as medicine and the toilet.

The separation by distillation of the hydrocarbons consists in raising the temperature when as the boiling point of each is approached it evaporates and is condensed by cooling. Two distinct methods are in vogue, the "Intermittent" and the "Continuous," the former being employed when the crude oil contains a high percentage of the more volatile constituents. For intermittent work the still is charged and heated gradually. As the temperature rises evaporation takes place, everything coming away below about 150° C. being classed as a motor spirit

or solvent spirit. The process being gradual allows fractions to be removed in stages so that there may be many "Grades" corresponding to the different proportions of low and high boiling point members. The "Spirit" portion having been removed the burning oils come next as the temperature rises to about 300° C. Here again there can be grading giving the many paraffin oils sold under various well-known names. Next come the Heavy Oils or Fuel Oils and Lubricating Oils and after their removal there remain Vaselines and Waxes.

In the continuous process there is a series of stills connected together, each succeeding one at a lower level than its predecessor and each kept at a fixed temperature. The crude oil flows slowly through the series at a rate that can be regulated so as to ensure the entire removal of each fraction before passing to the still of higher temperature. Each process has its special advantages for the commercial end in view depending on the nature of the raw material and the requirements of the finished product, but generally speaking the Intermittent method is more usual in the West than in the East.

There is a great difference in the amounts of the various fractions obtainable from oils of different localities. It is the same with coal, some districts produce Anthracites, others Bituminous Coals. The Spirit fraction may be as low as 5% or over 20%, burning oil is more uniform in amount, varying from about 20% to 40%, whilst heavy oils are from 30% to over 70%.

A matter that must receive careful consideration in Industry is the preservation of a satisfactory balance between high and low-value products. Waste material must be avoided, waste time and waste power prevented. In the oil industry the demand for the different fractions is liable to change as custom, habits change or as new

inventions are discovered. The increase in the number of motor cars and aeroplanes creates greater demand for motor spirit. Unless there is a corresponding increase in the demand for the other fractions the balance is upset and prices must be increased. To overcome this difficulty research has been carried on with the object of breaking down the higher fractions into the lower; this is known as "Cracking." There are many processes in use the majority of them depending on Catalysis. The catalysts employed are metals such as Nickel, Copper, Iron and Aluminium. The vaporized oil, either alone or mixed with steam, is passed over the catalyst heated to a moderately high temperature. The products obtained differ considerably according to the composition of the oil to be cracked, but there is a valuable yield of the more volatile hydrocarbons suitable for motor spirit. In the majority of modern systems the tendency is to produce paraffins and olefines at moderate temperatures, but at very high temperatures benzenes like those of coal tar are obtained.

It is important that oils for use in internal combustion engines shall be free from impurities that may cause injury to the metal surfaces at the high temperature of the explosion. One such impurity is sulphur. There are many mineral oil supplies that cannot be used for this reason. Much research has been carried out with the object of freeing the oil from this injurious impurity. It is not merely a question of its removal—that is easily possible—but of its cost. An expensive process means that the oil cannot compete in the markets of the world with oils that are sulphur-free. The discovery of a really cheap method for the removal of sulphur would bring many oils into use for motor purposes that are banned at present.

One cannot help wondering whether the world is using its oil supplies wisely, whether we are guilty of an unnecessary extravagance in the use of our oil supplies as we have been with our coal. There are millions of tons of coal in this country alone that can never be raised because of reckless methods employed in past days. Out of the bounty of a beneficent Providence we are driving our machinery, propelling our cars, navigating sea and air with materials stored in the earth before it was fit for human habitation. Are we justified in satisfying our desire for rapidity of transit by the too lavish use of our oil supplies? Unless the Inorganic Theory of the origin of oil is correct there is no probability that any is being produced to-day. In using it we are depleting our Capital and there is need to pause to consider whether our progress is at too great a cost. Many conflicting estimates of the World's oil supplies have been made from time to time. It is quite possible that all are below the mark, but in any case there is a limit.

There is an alternative to oil and that is Alcohol. It can be easily and cheaply manufactured by the fermentation and distillation of various substances of vegetable origin. Motors have been built that can use it and there is little doubt that if the demand arose they would become as efficient as those now using oil. There does not appear to be any scientific objection to its use, it is its Excise value that stands in the way. If it could only be rendered so unpalatable as to debar it from use as a beverage without at the same time destroying its motor efficiency there does not seem to be any reason why it should not eventually take the place of oil or at any rate considerably reduce our oil requirements and therefore help us to earn the gratitude of posterity.

CHAPTER XIII

THE TWENTIETH CENTURY

A SURVEY of the scientific achievements of the century cannot fail to produce a sensation of pride and admiration for the many who have contributed to them. Problems have been solved, difficulties have been overcome that seemed insuperable, but we seem to be no nearer finality. Every success attained has brought new problems which still await solution.

At the beginning of the century the air was still unconquered, prizes of several thousands of pounds had been offered for many years to anyone who would make a flight of about 1 mile in a heavier-than-air machine and return to his starting point. During a great part of the previous century the prospects of such an achievement had been debated. Early in the century it was confidently asserted even by scientists of note that it was impossible. The great mathematician Sir G. Cayley described the form the supporting surfaces should have if ever the problem should be solved. The flight of birds was closely studied, especially the large soaring birds, such as the albatross. Investigation shewed that their wings had certain features in common; they were long from tip to tip and were comparatively narrow from front to rear, i.e., they had a large " Span " and a small " Chord." The ratio of span to chord is known as the " Aspect Ratio "; if the span is ten times the chord the aspect ratio is 10. The bird with greatest aspect ratio for its wings—about 16—is the Albatross, that with the smallest—about 4—is the skylark, and it is not a soaring bird in spite of what the Poet says. Whilst it is in the air its wings are constantly fluttering.

Having discovered these facts many experimenters constructed small models, designed in accordance with the outstretched wings of a soaring bird. About the middle of the century Stringfellow of Somerset constructed a large one with a steam engine, but after a few partial successes further attempts were abandoned.

It was not until Otto Lilienthal made his famous glider flights about 1885 that promise of success appeared. His glider was fashioned on the shape of the outstretched wings of an eagle. Starting from an elevation with an opposing wind he succeeded in making glides of about 150 yards, sometimes rising to moderate heights, but eventually lost his life from a fall. The time was not yet ripe for the power-driven machine, it was waiting for the invention of the internal combustion engine which eventually came, first the gas engine and then the petrol engine.

Research and experiment were being carried out by a hard-working band of enthusiasts, among whom should be mentioned Prof. Langley, Octave Chanute and the two brothers Wright in America; Capt. Ferber, Archdeacon and the two brothers Voisin in France; Col. Cody, Moore-Brabazon and A. V. Roe in England.

In January, 1908, Henry Farman using a Voisin machine won the first of the money prizes by a flight (!) of about half a mile, during which he was not higher than the tree tops. This was done near Paris.

About this time we used to read in the papers that two young men named Wright in America had remained in the air for as long as 5 minutes (!) but we thought this was a fairy tale. The Wright brothers declined to give a public demonstration until financial reasons compelled them. In September, 1908, near Paris, Wilbur Wright remained aloft for over 1½ hours. The air was conquered at last.

In July, 1909, a body of anxious watchers on the

Channel coast of France saw Henri Blériot ascend into the air in his small monoplane and disappear. Shortly afterwards they heard of his safe arrival at Dover. The Channel had been crossed. The following day in London Blériot received the *Daily Mail* prize of £1,000 for his epoch-making feat.

On July 25th, 1934, a British pilot flew across the same track *upside down* in 16 minutes.

From that time progress has been rapid, but in the early part of it the toll of life was great. Machines were too lightly built, engine power was low, every ounce of weight thought possible was sacrificed and a sudden unforeseen strain brought disaster. The French flyer Pégoud did much to give confidence in the air. After several unsuccessful appeals he induced Blériot, whose machines he was using, to build one specially strengthened according to his requirements. He then took it to a height of 2,000 feet and deliberately capsized it, in spite of which he made a safe landing. He had proved, by risking his own life, that if a machine is made sufficiently strong to bear the strain, and if it is not too near the ground, it can be got under control from almost any position. We have all witnessed the wonderful acrobatics performed with modern machines, looping, rolling, inverted flying, all shewing the wonderful stability and power of control of the modern airplane.

Modern development is in the direction of increase of size and power. History is repeating itself in more than one direction. The ships with which Columbus crossed the Atlantic in his voyage of discovery were insignificant compared with giant liners of to-day. High endeavour has over and over again silenced the croaking of pessimism. There is little doubt that we shall see a similar advance in the air. Giant air liners of the future will make present

machines appear as pygmies. At present schemes are being considered for the provision of landing and re-fuelling stations at suitable points in the Atlantic so that regular services can be established between Europe and America. Already the British Empire is linked up by air, all the countries of the world are alive to the value of the new means of inter-communication. Air liners for moderate distances run to schedule time with the regularity of railway trains. Already the fear of danger has largely disappeared, the world is becoming air-minded, the relative loss of life on air-routes is less than on the roads and will become still less as heavy oil engines take the place of petrol engines. Early ships were all built of wood, the use of iron for the purpose was confidently regarded as doomed to failure. Early airplanes were all constructed of wood and canvas, the tendency to-day is for all metal.

We must not lose sight of the possibility that the air-plane of the future will not be of the fixed-wing type. Research is still going on to develop the moving-wing type. The "Autogiro" has passed beyond the experimental stage. One of the great problems of the day is that of starting or landing in a restricted space which is not possible with fixed wings.

Chemistry and Physics during the century have achieved much, even if their problems to-day seem as great as ever. Let us take a bird's-eye view of some of their achievements. We purposely class them together because their old mark of division no longer exists. They are so interlinked that it is often very difficult to decide where one begins and the other ends.

At the beginning of the century the atom was largely a hypothesis, it was emerging into reality; to-day it is a definite thing with form and size. It can be measured,

much is known of its internal structure, even the line of flight of a single one can be photographed. It is no longer the placid, self-contained, indivisible entity of old, it is a complex system made up of parts, it can be pulled to pieces and rebuilt into something else. In place of the unchangeable thing of former days it is sometimes the scene of turmoil and stress and instability that it can no longer hold together but has to break asunder and give us the phenomena of radioactivity.

Another realisation of the century is great " Emptiness " of matter. We have to regard solidity from a different standpoint. However solid a thing may look and feel, it is nothing but a collection of molecules and atoms with relatively big spaces between. The molecules too are very empty, mere frameworks like a skeleton building, and the very materials of the framework, the atoms, are skeletons also. Their protons, electrons, neutrons, positrons are separated from one another by relatively vast open spaces. Our stone walls have become mere open-meshed network. What a different outlook for the mental eye of modern science !

In 1901 the first Wireless signal was sent across the Atlantic, during the subsequent periods the development of Radio-telegraphy and Radio-telephony have been phenomenal. Until 1920 few but experts and technicians had any interest in it, but with the advent of broadcasting public interest was aroused and to-day it is world-wide. An important event in any part of the world is now known everywhere almost as soon as it happens. Governments, politicians and any others who may have news or views of note to impart can get in direct touch with the whole world, navigation of sea and air can be assisted in a way never dreamt of a few years back. The world has become smaller.

Television too is coming rapidly, some will say it has arrived. It is perfectly true that a distant scene can be received but there is much to be done before visual reception can be regarded as satisfactory. It has already been pointed out that objects are visible either because they emit or reflect light. Generally we see things for the latter reason. Different degrees of light and shade have different reflecting powers, different quantities of light come from the light and dark portions. Our eyes translate these differences into vision. For television an artificial eye is required. Certain substances such as Selenium and the Alkali Metals (Sodium, Potassium, etc.) have their electrical qualities varied by different amounts of light falling upon them. Devices designed to make use of this property are known as " Photo-electric Cells." If an electric circuit has a Photo-cell in it the current will vary in accordance with the amount of light falling on the Cell.

The scene to be televised must be " chopped up " into as many little bits as possible, each little piece must send its light to the Photo Cell which must convert the light effect into a corresponding electrical effect and all the little effects must be put together again by the receiver as lights of varying degrees of brightness on the receiving screen. It is like cutting up a picture into a " Jigsaw " of small pieces and fitting them together again. If it can be done quickly enough we get the moving picture just as we do in the Cinema. We older ones know how the early cinema pictures flickered and were deficient in sharpness. That is the position of Television to-day. The difficulty will be overcome, the scene capable of being televised will be enlarged, but much experimental work is necessary before perfect success is achieved. Those who can compare the Radio-telegraphy of the beginning of the

century with that of to-day will realize the possibilities of television a few years hence.

A new discovery may at any moment provide the required solution of the problem. A key may be found that will unlock the door and disclose the hidden secret. It was so in the case of Radio-telephony. With the old detectors, good as they were, the range of transmission was limited, enormous power was required to cover long distances because the loss was great. It was like undertaking a long journey in coaching days without relays of fresh horses. The discovery of the Oscillation Valve changed all that. A Hertzian radiation that was so enfeebled by distance as to be quite incapable of producing a worth-while effect could now be re-energized not merely once but an indefinite number of times. The whole world could now be encompassed and modern Broadcasting became possible. Television needs a discovery that will produce a similar change. And the discovery will be made.

The century has seen another great change in scientific outlook in the " Quantum Theory " of Max Planck. The beginning of the 19th century saw the first serious blow given to the age-long belief in Continuity. Dalton shewed that matter is done up in separate packages. In the bulk it consists of a large number of them but when we reach the final limit we must take a whole package or none. His packages were molecules. As the century progressed the idea became firmly established but the dimensions of the packages decreased, first to atoms and now to even smaller things, electrons, protons and the rest. The packages are not all alike, but whatever the number of each that may go to make up matter as we meet with it we cannot have less than one of them.

The close of the century saw the same idea extended

to Electricity; it too proves to be atomic, made up of a vast number of separate entities. An electric current is a procession of them. Platoons of troops in single file might represent feeble currents, companies in column of fours stronger currents, whilst brigades and army corps might feature heavy currents. But in each case the whole is made up of a collection of separate entities distinct from its neighbours.

At the beginning of the 20th century Max Planck carried discontinuity still further. He shewed that many of the difficulties connected with radiation of Energy could be solved by considering it also to be atomic. We have been accustomed for so long to regard heat and light as flowing steadily along, not broken up into a vast procession of separate units, that we have been reluctant to change our outlook. But in the light of the extension of modern knowledge there seems to be no alternative but to accept it. Light in addition to rendering objects visible does work. It can exert pressure, break up molecules as it does in photography, drive out electrons from metal surfaces as in photo-electric cells and in other ways demonstrate its energetic character. Other radiations also possess similar powers. The old idea of a continuously advancing stream could not give a satisfactory explanation of observed facts. Hence Planck's Quantum Theory. According to this, radiation of every kind is composed of a stream of separate units (Quanta), each one producing a certain definite effect. Energy is packed up in bundles of small size and when we reach the limit we must take a whole bundle or none, we cannot divide it up and make use of part of it. The Quantum Theory differs in one respect from the others in that the bundles (the Quanta) are not all alike, they vary in size with the frequency of the radiation. The quanta of red light are

smaller than those of violet light, they in turn being smaller than those of X-rays, but in any particular kind of radiation all the quanta are alike. The Theory is not very old, it has proved its value in many directions, but like others it will no doubt undergo modification as time goes on.

Although the Quantum Theory seems to have established itself it need not intrude into our outlook on the world at large. We need not bother about the atoms in a ton of coal or a pound of butter; for many of our everyday purposes an electric current behaves like a continuous stream and we can regard it as such, we need not analyse in into its separate electrons any more than we need to dissociate a stream of water into its separate drops. We can quite well look upon a beam of light or of X-rays as a continuous stream for most purposes, it is only when we have to probe into the reasons for certain effects that we need to trouble about the Quanta.

Apart from the academic side of the century's progress much has been done in contributing to the general well-being. A bare indication of some of the applications of this progress will suffice in concluding the chapter.

In the metallurgical industries science has played an important part. A time comes when metallic ores cease to be of paying value. If it is going to cost 30/- to get a pound's worth of gold from an ore it is left in the ground. Metalliferous mines all over the world have to be abandoned because only poor grade ore is left. Science has discovered a way of treating such low grade ores. The process is closely allied to a branch of chemistry that has many modern-day applications, viz., "Colloid Chemistry," concerned with substances in the form of jellies, slimes and liquids in which solids are suspended in such a fine state of division as to be imperceptible. If

an ore is ground up and thoroughly mingled with a froth of oil, on standing the less valuable earthy portions sink and the more valuable metallic ores remain floating in the oily mass and can be removed and refined. This is known as the " Flotation " process for low grade ores.

Alloys of many kinds have received much attention. Light ones containing Aluminium, Magnesium and Beryllium for use with aircraft where lightness combined with strength is all important are now in regular use. Research in connexion with Alloy Steels has given us the rustless variety in general use in house construction, furniture and domestic appliances. Hard steels necessary for engineering for high speed cutting machines and tools have been obtained by the alloying with iron of other metals such as Nickel, Manganese, Chromium, Vanadium, Tungsten.

Bio-Chemistry has played its part in the study of nutrition and food values. The Vitamins have been discovered, their action in controlling bodily functions has been studied, in some cases their artificial production has been effected.

Much food of a perishable nature comes to us from overseas. Its preservation by refrigeration calls for research into the economical production of low temperatures. The possibility of changes in nutritive value and of vitamin content during long storage also are carefully considered. Low Temperature Research Stations take note of such matters.

The demand for Artificial Silk has grown to huge dimensions. Its production calls for continual research for improvement in methods of converting cellulose into fibre of silk-like texture that shall possess durability, ability to withstand laundering, easy and fast dyeing.

Great as has been its progress during the century

Science is not relaxing its efforts. Its field of operations is ever widening. Discoveries made in the realm of Pure Science where the purpose to add to the store of knowledge, to seek after Truth, may at any time find an industrial application, research of any kind may confer benefits on the Arts, Industries and the amenities of modern life.

INDEX